Toward cost-effective nearly zero energy buildings: The Dutch Situation

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To reduce the high energy demand and pollution of greenhouse gasses of the built environment, the Energy Performance of Building Directive came in 2010 with plans for the European Union member states. Buildings must be, according the plan, nearly zero energy and should reach this goal by implementing cost-effective (passive-) measures for a high energy performance and application of sustainable energy source(s) for the remaining demand. In this research, a study is done on recently completed Dutch sustainable and nearly zero energy buildings, from which can be concluded that the goal from the Energy Performance of Building Directive now is rarely met. Most buildings use aquifer thermal storage system with a heat pump and thermal activated building systems. However, to really meet the nearly zero energy and low CO_2 emissions goal, in 2019 for public buildings and 2021 for all buildings, more focus is needed from the design teams in the early design phase toward cost-effective solutions. Life cycle costs are an important decision driver for achieving a cost-effective, nearly zero energy building. A new method, which incorporates additional benefits as productivity increase, sick leave reductions, Public Relations, and higher renting value, reveals that then an "economic optimal nearly zero energy building" can be met easier in the near future.

Introduction

Buildings account for about 40% of the total energy consumption in the union and about 36% of the CO_2 emissions in Europe (BPIE 2015). These CO_2 emissions are often related to the climate change and global warming. To reduce energy consumption and carbon emissions, the European Union (EU) established the Energy Performance of Building Directive (EPBD; EPBD 2010). This initiative of the EU member states (MSs) and the European Commission was launched in 2005, it promotes improvement of the energy performance (EP) of buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness (EPBD 2010). The EPBD requires all newly built buildings to be nearly zero energy buildings (nZEBs) in 2020. Existing buildings will also have to comply with this regulation toward 2050. Each European MS has to work out a plan that includes an nZEB definition for different building functions, determining specific building requirements.

In 2009, the Dutch government started their so called UKP NESK program (UKP means unique chances projects and NESK means "toward energy neutral schools and offices"

[Naar Energieneutrale Scholen en Kantoren]) to stimulate innovation for energy neutral buildings. This program of the Dutch government gave in 2010 funding to projects which show exceptional innovation in the area of energy conservation, sustainability or organization within the building industry, see Table 1. Innovation is needed in the construction sector in order to make the transition to energy neutral building. The Ministry of Housing, Spatial Planning and the Environment is, therefore, giving support to 15 innovative projects in the commercial and industrial sector. The aim of the NESK scheme is to learn by experience with building for extreme energy efficiency in order to build energy neutral buildings in 2020 and to stimulate innovation. Agentschap NL will take care of supervising the projects, monitoring and evaluation, setting up a Community of Practice, master classes for leading figures and communication. The Ministry presented NESK certificates to the initiators of offices and schools that are acquiring experience in energy neutral commercial and industrial buildings. These projects are very innovative projects that already meet the energy requirements for 2020. These projects and organizations played as inspiring examples an important part in stimulating other leading figures and the mainstream in commercial and industrial building in The Netherlands.

The Dutch government has set out a plan to implement nZEB regulation for the coming years (2015/2017) and published the "National Plan to promote nZEBs" in September 2012 (BENG 2012) following the EPBD recast by indicating the understanding of an nZEB. The U.S. Department of Energy (DOE) defines ZEB as "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported

Table 1. UKP NESK office projects.

Project	Type	Location	Year	Special features of project
TNT Office	New office	Hoofddorp	2011	Cooperation between principle and project developer, bio heat power combination, heat pump, aquifer thermal energy storage
VillaFlora	New office	Venlo	2012	Technology from greenhouses applied, bio heat power combination, heat pump, aquifer thermal energy storage
CBW-Mitex	New office	Zeist	2013	Performance contracting to guarantee an energy neutral office building, heat pump, aquifer thermal energy storage

energy." Therefore, the definition is based on annual balance of delivered and exported primary energy (DOE 2015). This definition equals to Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) nZEB definition (REHVA 2013): "Non-renewable primary energy of 0 kWh/(m^2 a)." Both DOE and REHVA provide an explanation that ZEB is typically a grid-connected building that is very energy efficient. The premise is that ZEBs use the electric grid or other energy networks to transfer any surplus of on-site renewable energy to other users (Kurnitski and Hogeling 2015).

The definition of a nZEB is described within the EPBD recast of the EU (ECEEE 2014) and it is specified that by December 31, 2020, all new buildings shall be nZEBs. Governmental buildings occupied and owned by public authorities will have to be nZEBs by December 31 2018, according to the EPBD recast. A definition of nZEB is based on the EPBD is the interpretation by REHVA:

Nearly Zero Energy Building (nZEB): Technical and reasonably achievable national energy use of >0 kWh/(m^{2}a) but no more than a national limit value of non-renewable primary energy, achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal.

One of these targets, described in articles 2 and 9 of the EPBD (2010), is that all new buildings after December 31, 2020 must be an nZEB and for the buildings of public authorities this is already after December 31, 2018 (see Figure 1).

These buildings should have very high EP and requires on-site or nearby renewable energy sources (RES) to a reach a nearly zero energy footprint.

Each individual MS must define their own strategy to comply with these articles for new buildings. Most countries in the EU use the annual primary energy demand as performance criterion. It implies the buildings energy demand due HVAC, hot tap water, and lightning. Some MSs does also add electrical plug loads into the primary energy demand definition. This primary energy demand must be as low as possible (cost-effective) and the remaining demand must be covered with a significant amount of RES as stated by article 2 in EPBD (2010). In the Netherlands they use a specific building performance assessment method according the NEN 7120 (2012) standard. The resulting energy demand is shown in an energy performance coefficient (EPC) which must be nearly zero in 2020. Important to mention is that electrical appliances/plug-

loads, such as computers, printers, and electric vehicles, are not taken into account in the Dutch method.

Another assessment criterion is the yearly CO_2 pollution. The EPBD (2010) does not advise a maximum carbon footprint level; however, for example, the final draft BPIE (2011) *Principles for Nearly Zero-Energy Buildings*, does advise a carbon foot print level of 3 kg CO_2/m^2 × y. But research (Taylor 2013) does show this is a very ambitious scenario since U.K. buildings do already not meet the "current (2013)" design requirements, see Table 2.

The "nearly" in the nZEB definition gave some confusion for MS to form a strategic plan. The word was introduced, because zero energy can technically be reached, but this is financially not (yet) desirable.

The Affirmative Integrated Energy Design Action (AIDA 2013) project aims to accelerate the market entry of nZEBs. One of their actions was defining nZEB design performance conditions as shown below:

- Limit the primary energy consumption to 50–60 kWh/m^2 × year or lower
- Of which 50 to 70% are covered by RES
- Limit the CO_2 emission: 3–8 kg CO_2/m^2 × year

This article presents an overview of the nZEB offices built in the last years. It shows that already an important step can be made from low-energy offices toward nZEB.

Nearly zero energy buildings

More than one-quarter of the buildings which exist in 2050 have to be built according to the Chartered Institution of Building Services Engineers (Taylor 2013); the other 75% need

Table 2. Building carbon footprint design target 2013 and 2013 operating values.

	EPBD [2] 2020 Kg × CO_2/ (m^2 × y)	UK Design target 2013 Kg × CO_2/ (m^2 × y)	Operates now (2013) Kg × CO_2/ (m^2 × y)	Miss their design target (already) with [%]
Schools	3	30	50	67%
Universities	3	40	100	250%
Office	3	50	75	50%

a significant upgrade. The Building Directive (EPBD 2010) promotes the improvement of the EP of buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness (EPBD 2010). It is a very flexible policy requirement with no single, harmonized nZEB definition throughout the EU (ECEEE 2014). The main goal is to minimize the green-house gas emissions of the built environment by the following "equation:"

$$\text{nZEB} = \text{very high EP} + \text{on-site and/or nearby RES}$$

The EPBD 2010, as such, does not require on-site or nearby RES. This is interpretation of the EPBD was made by REHVA and others. What is actually stated in the EPBD (2010) is that the "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." This means that the renewable energy can also be supplied from far away, for example, hydropower or windpower. But when calculating the extent of renewable sources one shall not forget the energy from renewable sources produced on-site or nearby, for example, heat extracted from the ground by a heat pump. This also means that the given equation is not a strictly correct definition of nZEB according to EPBD (2010). However, it could be used to minimize the green-house gas emissions.

Many European countries still have not completely fixed the nZEB targets in a legal document (ECEEE 2014) and the "innovative" renewable energy measures which are included by the MSs in their nZEB application are as following; Solar thermal 18 MS, Photovoltaic (PV cells) 17 MS, passive solar, day-lighting, biomass 16 MS, heat recovery, passive cooling, and geothermal 15 MS., Biogas 14 MS, micro-wind generator, micro-combined heat power (CHP), ambient air (in air-to-air heat pumps) and bio fuel 13 MS, waste heat (from industries, computer server rooms) and solar cooling 9 MS. Waste heat from hot water (bath/shower, washing machines) 6 MS. This shows there is still room for improvement.

According to the EPBD recast, the metric of the balance for an nZEB is primary energy (Voss and Sartori 2012). Some MS prefer carbon emissions as the primary metric, for those

countries weighing factors are given in an EU standard as the EN 15603. The building Performance Institute Europe (BPIE 2014) provides a useful diagram (Figure 2) to understand the principles in the broader political context. It uses the Trias Energetica principles to explain the nZEB approach in more detail and clearly indicates that cost-optimization (Figure 3) is the main driver for the "nearly" approach.

In the EPBD, energy balance calculations take into account the technical services for heating, cooling, ventilation, and domestic hot water (and lighting in the case of nondomestic buildings; Voss and Sartori 2012. On-site generated renewable energy can be exported or directly self-consumed. This local load and production match and grid-interaction will become important factors for future smart-grids. The interaction can be used for dynamic, time-dependent, weighting factors (Figure 4). It doesn't mean that an nZEB connected to the grid would have zero costs (cost of grid use, dynamic inport/export tariff and taxes), see Figure 5.

The performance assessment method used in the Netherlands is the "Energie Prestatie Norm voor Gebouwen" (EPG) according NEN 7120 (2012). The performance is assessed by an EPC, this is calculated by the characteristic primary building energy demand divided by the acceptable primary building energy demand, then multiplied by the EPC requirement (and a correction factor for specific building functions) at that moment. It gives an indication of the primary energy demand. However, one of the fixed input values in the EPC calculation is the building use, therefore, the different use of buildings is not taken into account, which results in difference between buildings caused by different user behavior. For example, nZEB buildings have a high insulation value and installation performance level where the energy demand is dynamic based on occupant behavior and climate conditions. Therefore, actual (in-use) EPC can differ substantially than the theoretical EPC, since occupant behavior is fixed. It is recommended that the primary energy demand is calculated with building performance simulation software with a transient engine (where events as mass activation, automatic blinds, and innovative materials are taken into account) where more input information can be given as occupant behavior and detailed HVAC installation behavior.
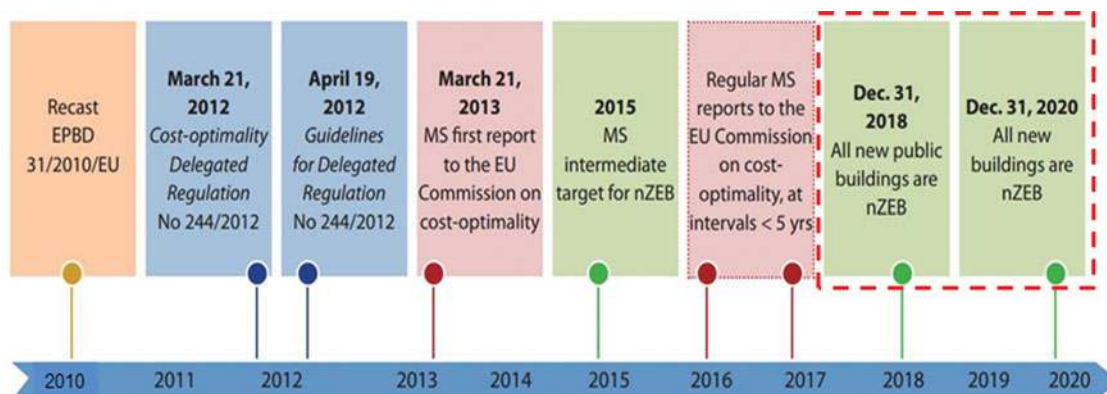

Fig. 1. Implementation timeline for cost-optimality and nZEB requirements of EBPD [NEN 7120 2012].
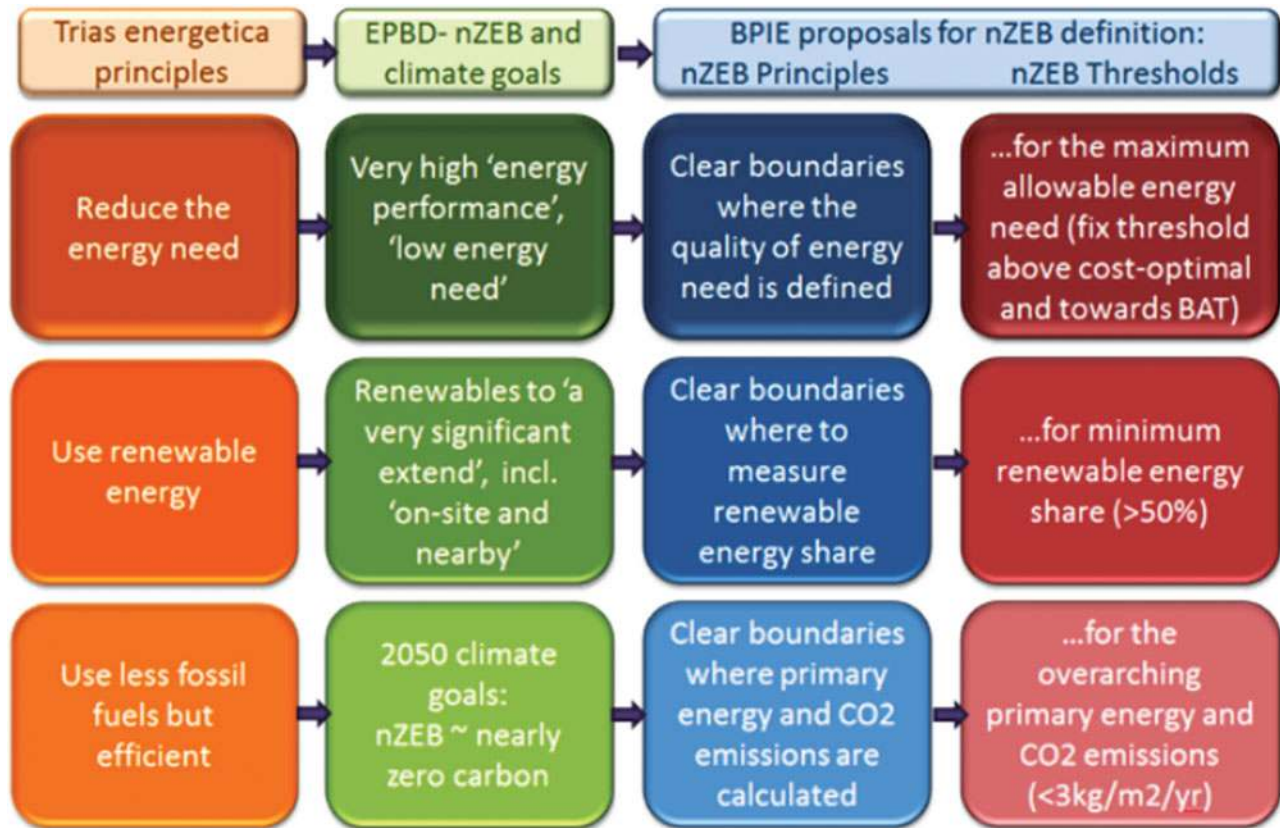
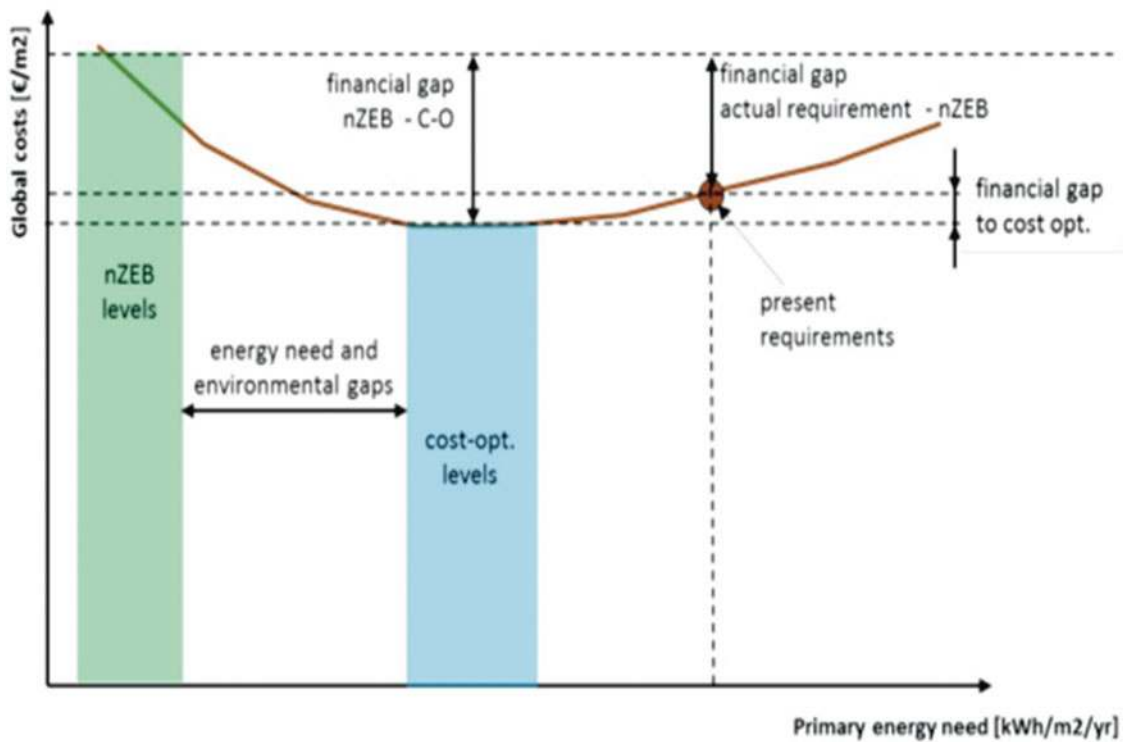**Fig. 2.** Principles for sustainable nZEB in the EU (BPIE 2014).

Fig. 3. Example in financial, energy, and environmental gaps between current and cost-optimal requirements and nZEB levels (BPIE 2014).
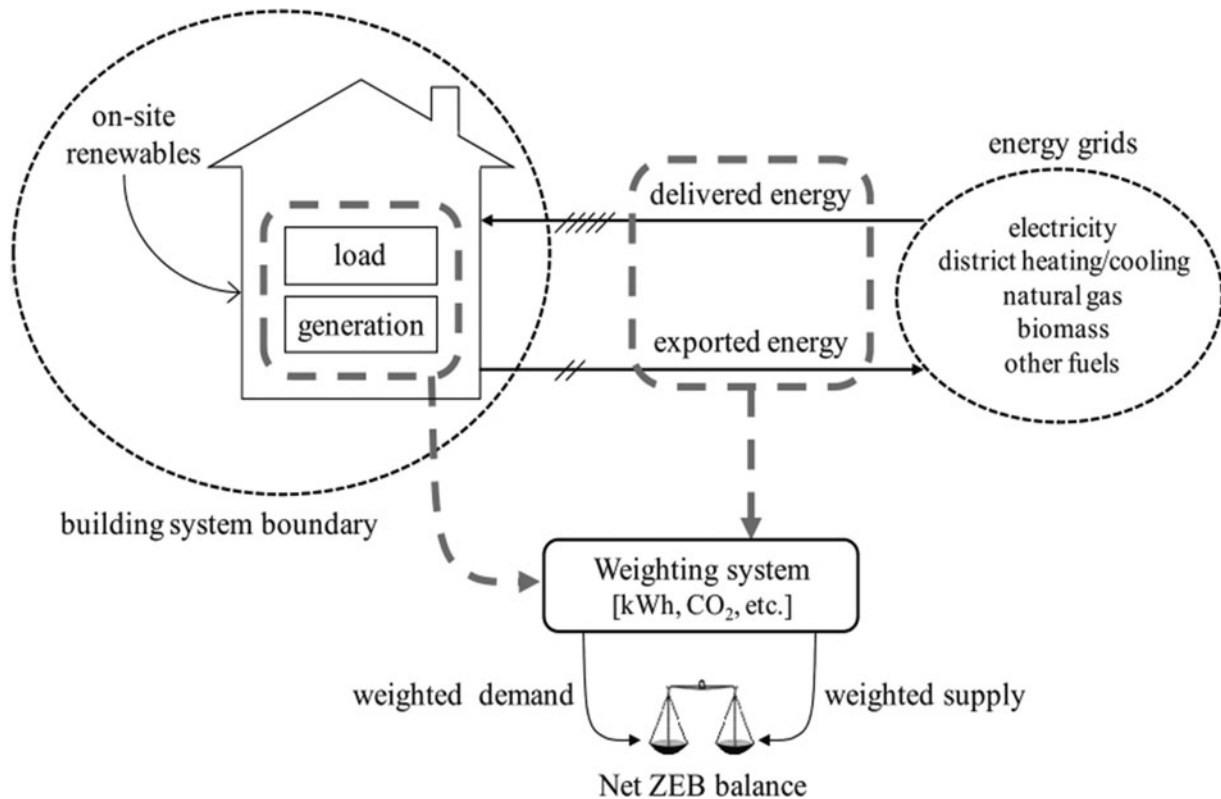
Fig. 4. Schematic overview of the connection between building and the grid (Voss and Sartori 2012).

Currently, the EPC is 0.4 for residential buildings and will be lowered further, to ultimately reach zero, according to a covenant of the new buildings sector, aimed at reducing the energy consumption of new buildings over time. In this signed agreement between the public and private sectors, a number of efforts have been agreed to reduce the energy use of new buildings by the year 2015 by at least 50% compared to 2007 levels.

The tightening EPC demands require a new and improved cost-effectiveness methodology, therefore, a practical and theoretical test has been developed for both residential and utility buildings. The focus points in this new methodology were to create a clear method for all building types, to adapt the existing method to new EU demands, and to include additional gains into the life cycle cost (LCC) calculation. The Sustainable Building Accelerator study (Zeiler et al. 2015) lies at the base of the enhance cost optimality calculation in which benefits are included next to costs (Maassen and Maaijen 2011). Cost-optimality calculations are essential for determining the Dutch nZEB definition, because they determine if the energy efficient measures are cost-effective and can be implemented in the building law.

In the near future, EPC requirements will be reduced to values that lay within the so-called "cost optimal range" as shown in Figure 6 (green area). This range is determined by calculating the LCCs over a period of 30 years. In 2020, all buildings will have to be nZEBs (blue area in Figure 6). The nZEB level is determined by each EU MS based on the economic feasibility. Current calculations show that nZEBs will result in much higher LCC values than the economic optimum. Therefore, a

LCC method which also takes additional gains (e.g., productivity, resale value) into account is proposed. Including these gains leads to lower total LCCs and the economic optimum shifts toward nZEB requirements (blue arrow in Figure 6). Focusing on gains and including these in the LCC calculation method is an important foundation for the Roadmap toward nZEBs.

The cost-optimality is a crucial aspect for the introduction of nZEBs in the Netherlands. In 2009, the effects on lowering the EPC to 0.6 for residential buildings in 2011 were studied (dGmR 2009). The goal was to gain insight about the effect of EPC reduction on the indoor environment, energy demand, CO_2 emissions, the relation between investment costs and energy saving measures. In 2013, a follow-up study was done on cost optimality of energy saving measures for residential and utility building according to the EU calculation method (dGmR 2013). The results for the financial and macro-economic calculation were quite similar, so only the results for financial cost optimality analysis will be discussed later in the article. The following graphs show the additional net constant costs (NCC) for different packages (energy saving measures) compared to the EPC (Q/Q) demand of different building types/functions. To satisfy the EPC demand (from 2013), it is important that proposed measures result in a Q/Q below 1.00, see Figure 7.

It shows the additional net present values (NL; and NCC) for energy saving measures for office buildings. Almost all measure for office building satisfy the EPC demand and cost of energy saving measures prove to be cost neutral or even cost reducing. This means that all applied measures are
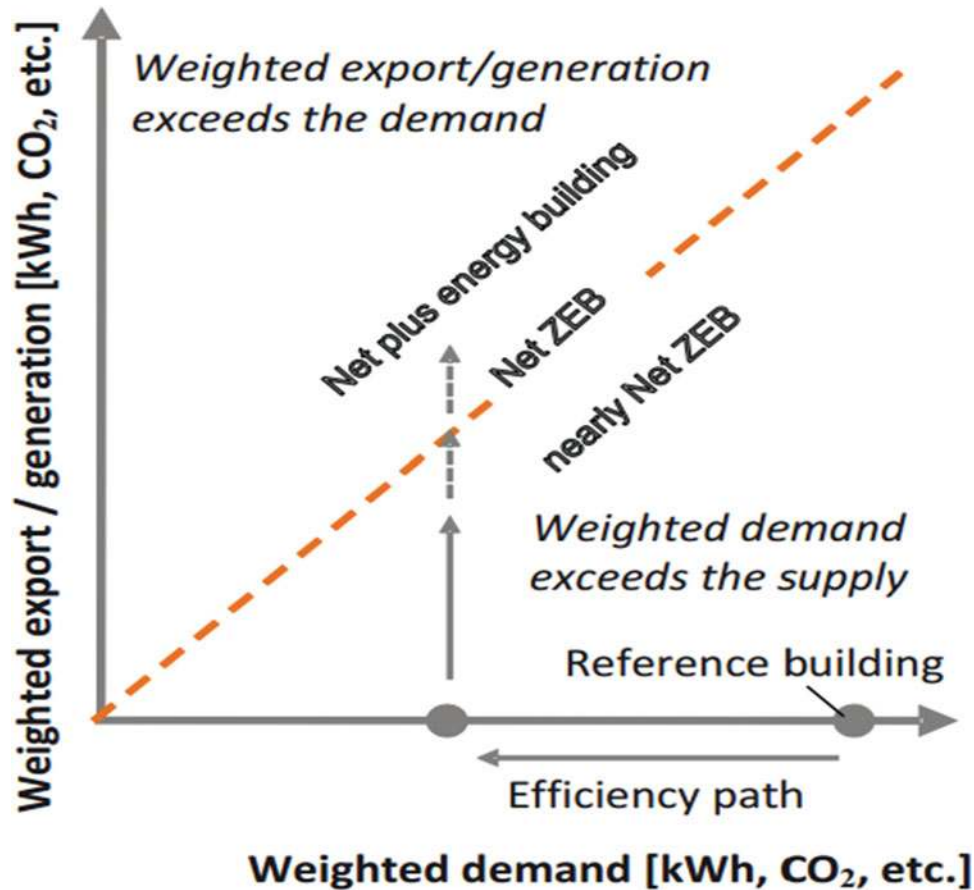
Fig. 5. The path toward a net zero energy building (Net ZEB), with the nearly and plus variants (Voss and Sartori 2012).

already cost-effective for an EPC of 0.65. The goal of this study is to provide nZEB scenarios with low EPC scores and primary energy consumption in combination with low LCC. Currently, cost optimality calculation can be made for existing technologies (Figure 8a).

These buildings are to conform to current EPC demand and are within the cost optimal range. Buildings that have to comply with future EPC regulation will have to be equipped with future technology. This will result in low primary energy demand (low EPC); however, these technologies are not yet cost-effective (Figure 8b). In order to reduce LCC, additional gains, such as resale value, productivity, etc., will be added to providing a new type of graph (Figure 8c) in which lower LCC and primary energy are accomplished. This new calculation method is called the LCC' since it is not exactly the same method as prescribed by the EU. The LCC' cost optimality calculations have been executed using the Sustainable Building Accelerator (RHDHV 2014; NL: "DUBO-versnelle"); a LCC calculation tool (Maassen and Maaijen 2011). The DUBO versneller tool can be utilized to compare the LCC of four buildings concepts to each other. The input of the DUBO takes four main expenses into account:

- **CAPEX** (capital expenses)pt in [€/m^2], e.g.,:
  Building costs
  Land costs

Installations: mechanical and electrical installations
Building creators: architect, installation advisors, building managers

- **Energy** in [€/(m^{2}a)], e.g.,:
  Electricity
  Gas

- **OPEX** (operational expenses) in [€/(m^{2}a)], e.g.,:
  Maintenance: building, mechanical, and electrical installations
  Other building services: cleaning
  Taxes, insurance

- **End value** in [€/m^2], e.g.,:
  Rest value of building
  Residual value: building, land, installations
  Dismounting and disposal

Dynamical input costs, including replacement of installation after x number of years, have also been integrated in LCC' calculation. This allows taking refurbishments and overhauling costs into account.

For the cost optimality calculation the discounted cash flow was used. The LCC' calculation method also provides a possibility to perform a sensitivity analysis for all variable parameters such as interest rate, discount rates, and energy prices. A web-based light version (NL) of the Sustainable Building Accelerator can be found at www.duboversneller.nl.
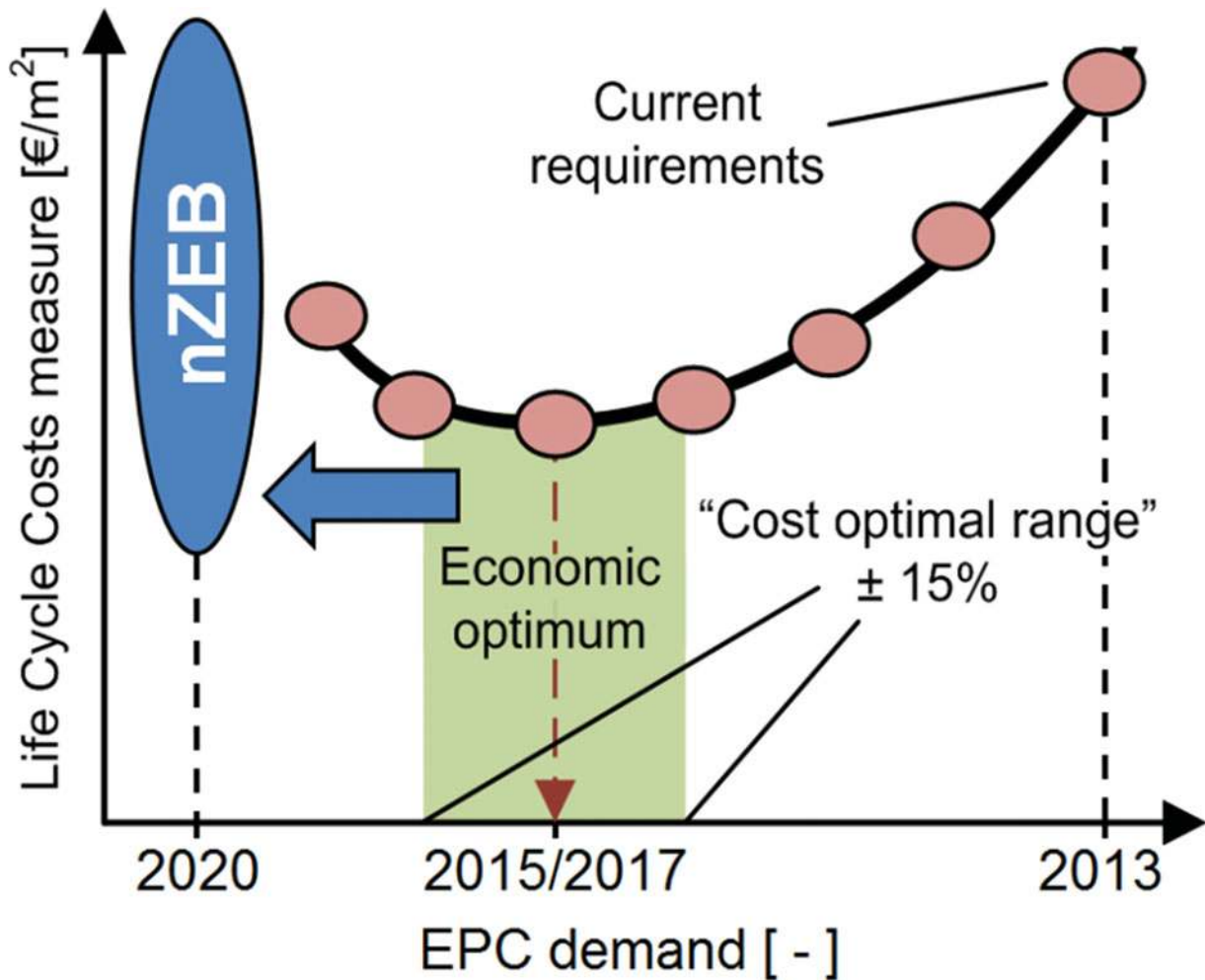
Fig. 6. Lice cycle costs versus the EPC-demand.

Energy prices used in the LCC' calculation have been determined using energy prices from three large energy suppliers for a middle sized office building. These costs are specified in [€/(m²a)].

Gas price

Energy saving measures applied to the nZEB scenarios results in all-electric buildings, which have no gas connection. Because the buildings are all electric, no differences appear (gas connection). When the nZEB scenarios would be compared to a gas-grid-connected building, cost can be further reduced. The energy demand in the cost optimality is expressed in primary energy a units, meaning primary energy has to be converted to cubic meter gas and kWh electricity. The following conversion values have been used: natural gas: 35.17 MJ primary energy per m³ natural gas; and electricity: 9.23 MJ primary energy per kWh. The electricity prices for utility buildings are distinguished for an annual consumption of <10,000, <50,000, and >50,000 kWh. These tariffs can affect the energy consumption when it is close to the set limit, and it will most certainly influence the PBP of PV panels.

Besides the OPEX, there are also benefits to be considered like:

- *Productivity increase*: The productivity increase was implemented using the cost-reduction value of 26.50 €/(m²a)
- *Sick leave reduction*: An average value was determined for sick leave reduction using the studies from Bergs (2010) and Fisk et al. (2004). According to the first study, sick leave by unhealthy climate works out to an average of 3.6 days per employee per year. The second study is more specific (only looking at effects of an economizer on energy and cost) and results in averaged 35 additional sick days (spread over 72 employees) when no economizer is installed. This number corresponds to 0.49 sick days per employee per year. The average value, used in the LCC' calculation, was 2.05 days per employee annually. The office building in the current study is assumed to have 200 employees (15 m²/employee) with a monthly salary of €2000.
- *Public relations (PR) value*: The quantification of costs for PR value may be calculated with the budgets companies use for publicity on sustainability. Normally money would be spent on improving a production process (making
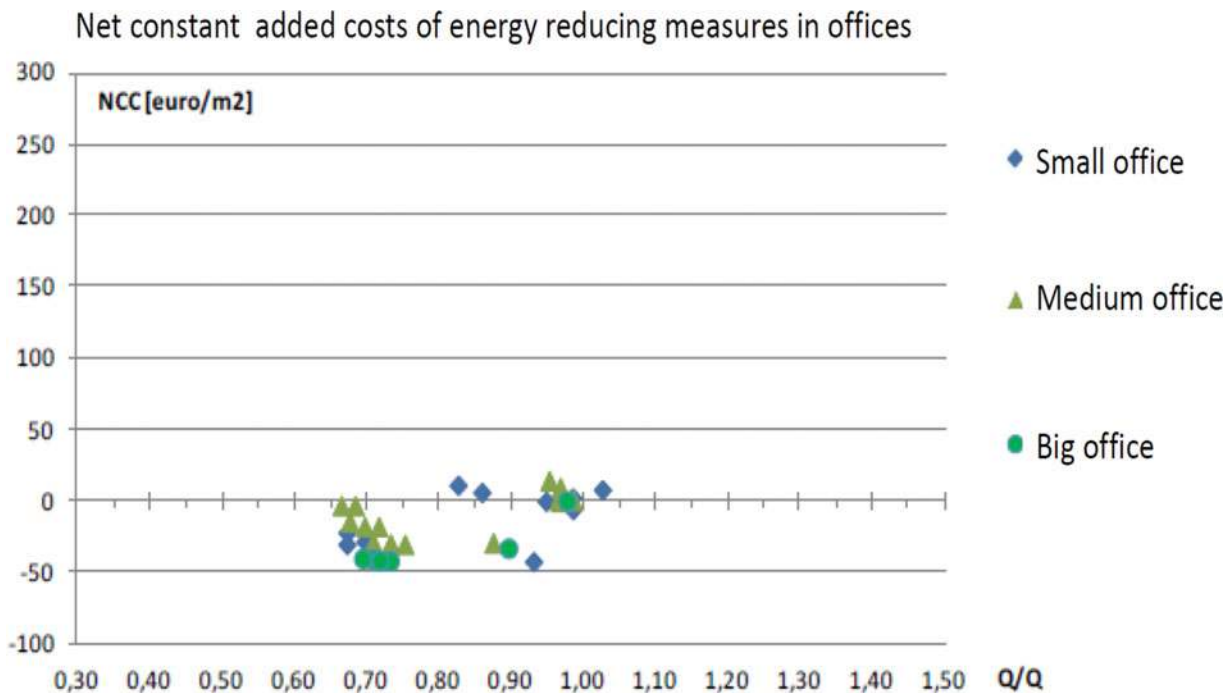
Fig. 7. The additional net present values of energy saving measures for office buildings (dGmR 2013).

products or services more energy efficient) which would be used for a greener image. The annual costs spending on those processes may now be spend a more sustainable building; the PR value of the building may be used for several years until regulation and other buildings have caught up to the nZEB standards.

- *Higher renting value*: This value is mostly represented by a combination of productivity increase, sick leave reduction, and PR value. The reason this is mentioned is that these costs may or may not be incorporated in the LCC' calculation, depending on whether the building owner is also the building user. When the building is rented, the higher rent-
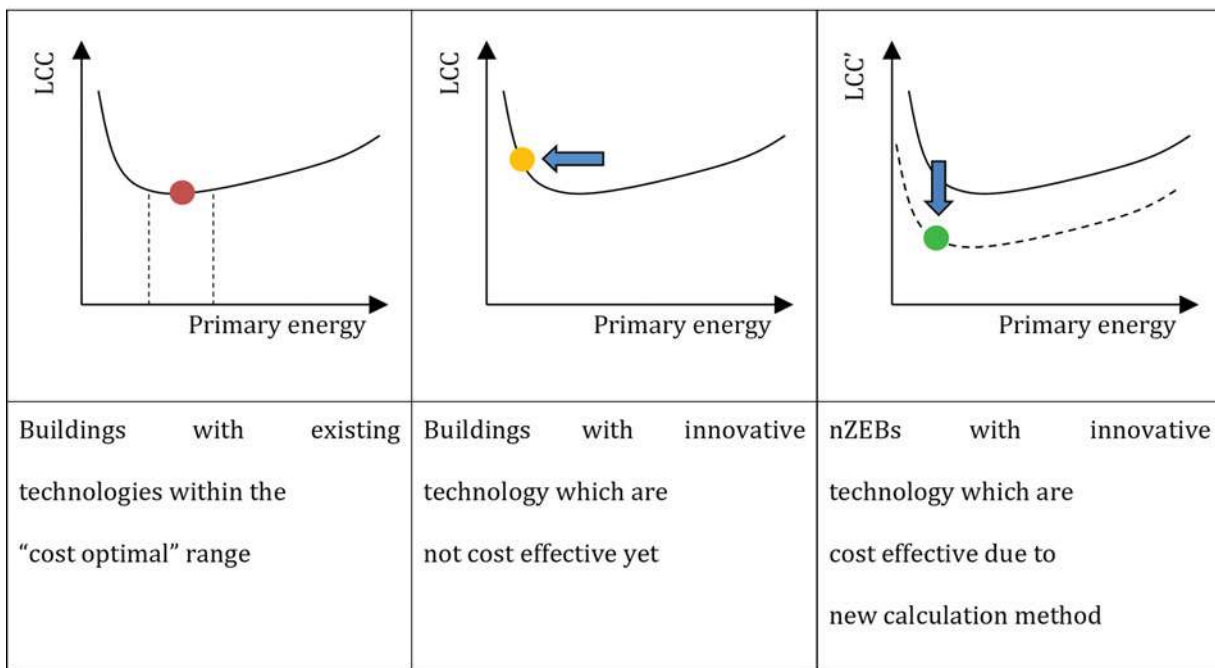
Fig. 8. Cost-optimality trajectory a. "standard" scenarios; b. scenario with innovative technologies; c. scenario with innovative technology and new LCC' calculation method.

ing value is most certainly lower than the combined gains (productivity, sick leave, and PR value) because it is quite difficult to charge higher rent when values on number of employees, salaries, PR budget, etc., cannot be determined. This leads to the conclusion that it is more advantageous to own an nZEB.

- *Higher rest value*: The value of building installation, such as the ground source well, for ground source heat pump (GSHP) or aquifer thermal energy storage (ATES) gives the building a higher end value. In the current study all buildings concepts (U_{ref}, U_1, U_2, U_3) have wells, therefore, costs/gains do not alter the outcomes of the LCC' calculation. However, the added value will be more significant when comparing nZEB scenarios with a conventional building with high efficiency gas boiler (no wells).

Critical parameters of the LCC' calculation, often calculated or assumed, will be tested using the sensitivity analysis. The analysis will have to satisfy minimum requirements according to the EPBD recast for different price scenarios for energy carriers (gas and electricity) and minimal two discount rates for the micro- and macro-economic analyses. The parameters may only be changed one at the time to see the changing effects. Values from (RHDHV 2013) were adapted according to the recalculated values of (Maaijen 2011).

The report from dGmR (2013) about cost-optimization in the Netherlands describes that the EPC-requirement can be 15% below or above the cost-optimal level. A new approach is explained in a research about the roadmap toward nZEBs. The cost optimal range is determined by calculating the LCCs over a period of 30 years, but current calculations show that nZEBs will result in much higher LCC values than the economic optimum. Therefore, additional benefits, such as productivity increase, sick leave reduction, PR, and higher renting value, should be taken into account in order to achieve an nZEB in 2020. The future policy timeline for nZEB and their EPC-demand is shown in Table 3 (RVO 2015).

The thermal envelope of a building should at least have the following insulation values from 2015:

- Floor: R_c-value of minimal 3.5 [$m^2 \times K/W$]
- Façade: R_c-value of minimal 4.5 [$m^2 \times K/W$]
- Roof: R_c-value of minimal 6.0 [$m^2 \times K/W$]
- Transparent constructions and doors: U-average facade [1.65 $W/m^2 \times K$], and individual part not higher than 2.2 [$W/m^2 \times K$]

It is expected that the primary energy demand requirements for Dutch residential buildings will be around 30 to 50 kWh/$m^2 \times$ y (EPC of 0.2 to 0.4; Gvozdenovic et al. 2014). The same research indicates that it is possible to have nZEB designs with an average energy consumption of 20 kWh/$m^2 \times$ y resulting in an EPC score of around 0.2.

The potential for nZEBs in the Netherlands is mainly determined by the availability of building energy saving measures. Currently, measures are applied according to the Trias Energetica method, see Figure 9. An adapted version of the Trias Energetica method should be used in the future because of changing conditions for buildings.

First of all, the focus should be on adapting the energy demand to the building user. Awareness should be raised and energy saving behavior should be stimulated by the government. Another step that is added is the implementation of energy exchange and storage systems (smart grids): These become crucially important for nZEB because of the intermittent characteristics of most RES. Energy exchange has great potential for reducing energy demand, especially when buildings with a specific heat or cold demand are combined (e.g., nursing homes and information and communication technology [ICT] data centers).

To reach the goals the report of roadmap to nZEB proposes an addition to the 3-step Trias Energetica design method by adding 2 steps (step 1 and 4 of the 5-step method), see Figure 9.

The first step focuses on the energy demand of the individual user, where normally energy demand is reduced by passive energy saving measures and other building performance improvements as LED-lightning and heat recovery techniques. Techniques that focus on the building user are (individual) climate zones, local ventilation systems, workplace thermal systems, presence detection, etc.

In earlier research (Maaijen et al. 2012) about the human in the loop approach, was found that with more than 20% energy savings can be achieved on heating demand and up to 40% energy savings on cooling demand compared with the actual energy demand. "In the used case study the human influence is 3–5 times higher than variations in building parameters."

Step 4: Efficient energy exchange by smart-grids and active loads (as a smart washing machine), rest-heat, storage in phase change materials (PCMs), electrochemical batteries, thermal energy storage, etc.

nZEBs in practice

The average Dutch office building has a primary energy demand of 900 MJ/m^2/year (250 kWh/m^2), which is way above the nearly zero energy demand limit AIDA (2013) proposes (50–60 kWh/m^2 of which 50–70% is covered by RES). The CO_2 emission of an average Dutch office building is 50 kg/co2/m2, which is almost 17 times as much as the BPIE (2015) states for an nZEB and about 6 times as high of the upper advised limit of AIDA (2013).

In an inspiration book about 15 sustainable Dutch offices (Peutz et al. 2014), only one building was found which falls between the advised boundary conditions (AIDA 2013) of nZEB. This example is the in 2011 completed building of the Dutch Institute of Ecology (NIOO-KNAW). This building has an expected primary energy demand (no real monitoring data available) of 45.3 kWh/m^2 (EPC = 0.3), 82% less than the national average, 21% of this energy demand is achieved by PV-energy; there are plans to extent the installed PV-capacity, this could transform it into an energy-neutral or even energy-plus building. The biggest fraction of the primary energy use goes to lightning and then to heating and ventilation, see Figure 10. This lightning power demand is higher than the national average of 29% (Figure 10) and for sustainable buildings 26%

Table 3. Future policy timeline (RVO 2015).

Year	EPC-demand Future policy			
	2015	2021	2030	2050
Residential buildings	0.4	≈0 All new buildings nZEB	30% of all buildings renovated (after 2015) have to be nZEB	80% decreased primary energy consumption compared to 1990
Offices	0.8			
Health, clinical	1.8			
Health, non-clinical	0.8	Governmental buildings should be nZEB in 2019		
Educational	0.7			
Retail	1.7			
Sports	0.9	5% of the existing buildings nZEB		
Meeting	1.1			

(Figure 10). While the average installed lightning capacity is only 1.5 W/m², in contrast to an average sustainable office building with an installed lightning capacity of 7–9 W/m². The building has an ATES system (with two cold and two warm, underground wells at a depth of 80 m[1]) and a high temperature underground thermal energy storage system (40–45°C at a depth of 300 m[1]). Heat is mainly generated with 478 m² solar collectors and an additional load can be derived from a heat pump. Cooling is withdrawn from the cold well and is generated by a dry cooler during cold periods or the evaporator of the heat pump. The CO_2 emission is estimated at 8 kg CO_2/m².

Practical examples of sustainable buildings

In the Netherlands almost all sustainable offices applies geothermal ATES systems for seasonal heat and cold storage, see Table 4. By this cooling and heating can be achieved with a relatively low primary energy consumption. Buildings constructed during the last decade have high standards of air-tightness and insulation. For all buildings these measures achieve a significant improvement in heating demand and comfort. For office (and comparable) buildings, however, there is an additional advantage.

Because office buildings typically have a high internal heat load (heat generated by people, lighting, and equipment), the
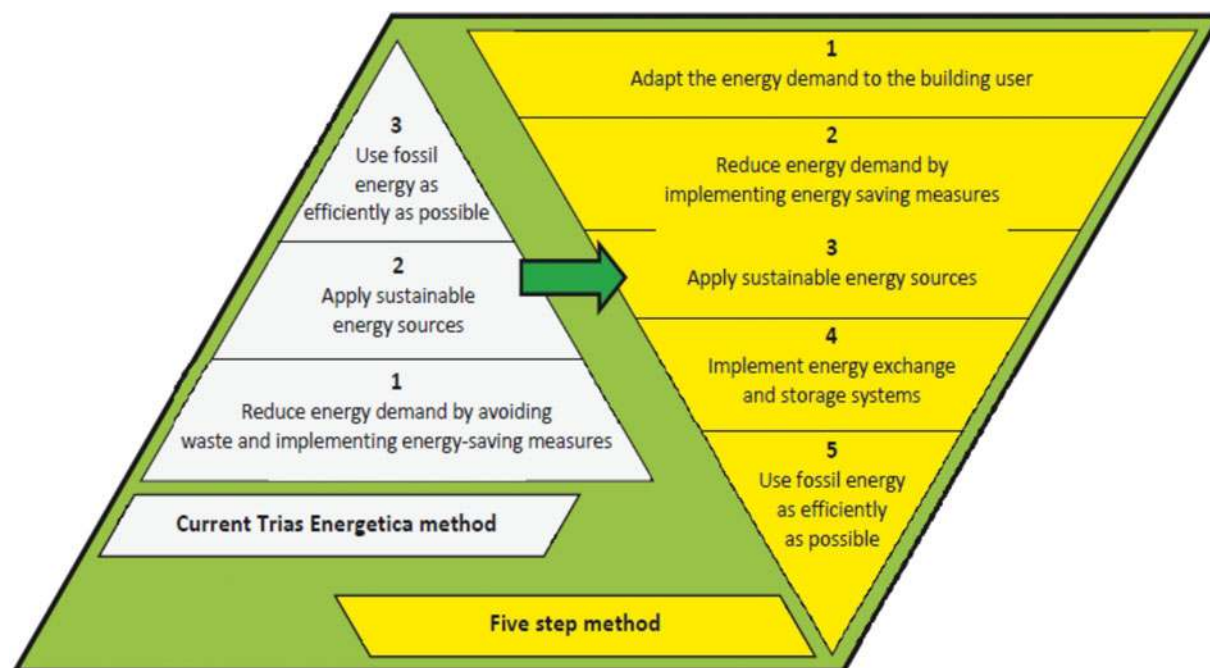

Fig. 9. The Trias Energetica method and the 5-step method (Gvozdenović et al. 2015).

Table 4. Comparison of office buildings in the Netherlands.

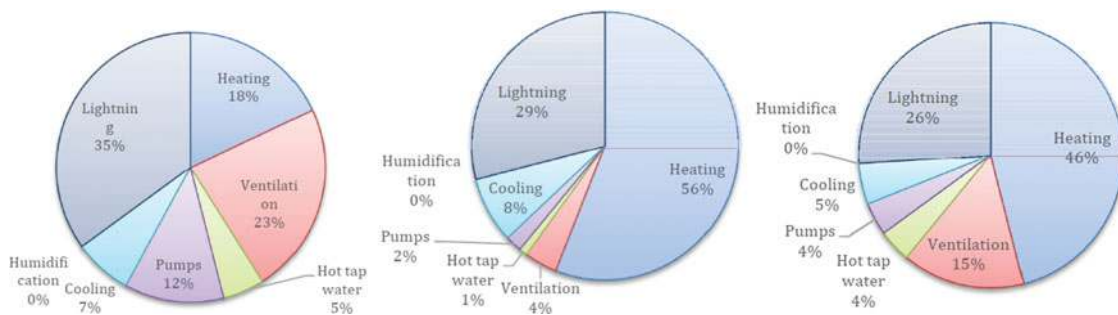|	Agency NL reference building 2015	Eneco office (Rotterdam) 2011	Enexis office (Venlo) 2012	NIOO/KNAW (Wageningen) 2011	Villa Flora (Venlo) 2011	TNT office (Hoofd-dorp) 2011	CBW Mitex (Zeist) 2011	Hitachi data (Zaltbom-mel) 2013	Venco campus (Eersel) 2012	Enexis (Venlo) 2013
Year										
Installations										
Heating	High efficiency gas boiler (107HR)	Electric heat pump & ATES with district heating	Electric heat pump & ATES with boiler (HR107)	Electric heat pump & ATES	Bio CHP, electric heat pump & ATES	Bio CHP, electric heat pump & ATES	Bio CHP, electric heat pump & ATES	Bio CHP, electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES with boiler (HR107)
Cooling	Compression cooling	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES	Electric heat pump & ATES
PV system	-	1140 m^2	2100 m^2				650 m^2	1000 m^2	5700 m^2	2100 m^2
EPC	0.6	0.72	0.0	0.4	0.38	0.67	0.0	−0.83	−0.298	−0.14

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Fig. 10. Average primary energy demand of the Dutch sustainable-office NIOO-KNAW of a Dutch office building and of Dutch "sustainable-offices" (Peutz et al. 2014).

required amount of external heat is relatively low compared to residential or utility buildings. As result, the required amount of cooling is significantly higher than the average building. Today, modern office buildings have reached the insulation quality at which the amount of cooling required during the summer roughly equals the amount of heating needed during the winter. Hypothetically this means that if all heat could be stored within the building, no external heat source would be needed throughout the year.

The storage of such large amounts of (low quality/temperature) heat within the building would require vast amounts of high heat capacity materials like thick stone walls (as in churches, castles) or PCMs. A more feasible option is to store the energy outside the building. An increasingly popular solution is energy storage in the groundwater below the building. This groundwater is stored in porous sand layers, called aquifers. Therefore, this method is called ATES. Using this method the seasonal storage effect of an expensive high thermal mass building can be achieved with a cheaper lightweight building construction and an external ATES system.

The principle of an ATES system is based on transferring groundwater between two separated storage wells. During summertime water is extracted from the coldest well and used to cool the building. During cooling, the water temperature increases from approximately 8°C to 16°C. The heated water is injected in the warmer well and stored until winter season. During winter the extraction/injection flow is reversed and the heated water (which still has a temperature of approximately 14°C) is pumped back to the building. The water is cooled to approximately 6°C and is injected in the cold well. A heat exchanger between the groundwater and the building system water is used to avoid contamination of the water. However, conventional ATES systems with high storage capacity are operating around 8–12°C in the cold well, 15–18°C in the hot well. Therefore, it is necessary to employ additional devices (heat pump, electric motor, etc.) to further increase or decrease the temperature. In using a heat pump, the heat is extracted and converted to the required temperatures to heat or cool the building.

The storage wells can be located horizontally or vertically spaced to each other (Figure 11). A horizontally spaced system is called a doublet and has the highest thermal capacity because the total length of the well can be used to inject or extract water. A vertically spaced system is called a mono-well.

A mono-well has less capacity, but is significantly cheaper because only one borehole is needed. This research will focus on a mono-well system, as this system is used at the Kropman Utrecht office (the used case study for this research).

For efficient and profitable application of a mono-well ATES system there are a few boundary conditions, which make the Dutch soil structure particularly suitable. The groundwater level should be relatively close to the ground level, to avoid expensive deep drilling. In the Netherlands the groundwater level is usually within 20 m below ground level. The natural flow in the groundwater should be low to avoid the stored heat/cold flowing away. Due to the flat Dutch landscape, the annual groundwater flow is only a few meters per year. To use two vertically spaced wells (a mono-well), there should be an impermeable layer of clay to avoid a short-cut water flow between the storage wells. A large part of the Dutch soil consists of alternating layers of sand and clay, making it likely that a suitable separation layer can be found. An optimal performing ATES system can deliver very efficient cooling. The case-study system for example uses a 2 kW well pump that delivers 20 m3/h of cooling water with a ΔT of 8 K between extraction and injection. This equals roughly 200 kW of cooling power, a coefficient of performance (COP) of 100. For comparison, a regular (compression-based) cooling system reaches a COP of between 4 and 6 (NEN 2012). The energy gains (compared to a conventional system) for heating are not that significant, because the stored low temperature heat is not directly applicable in the building. The heating performance of the ATES system depends mainly on the coupled heat pump, which has a COP of around 4 (NEN 2012). However, assuming an average Dutch electricity generation efficiency of 42% (Segers 2014), this is still a 60% higher efficiency than natural gas boilers and is required to provide the cold water storage supply.

Because of these favorable conditions, the use of ATES systems in the Netherlands has become increasingly popular since the first installations in 1990. In 2013 there were over 2000 installations in use and this number is expected to grow to 10.000 (worst-case) or 20.000 (best-case) in the year 2020 (Unica 2012).

ATES with high storage capacity is expected provide high amount of flexibility as it operates in seasonal mode. The capacity of ATES is not limited to a certain amount of energy since it is not restricted with geometrical boundaries; whereas
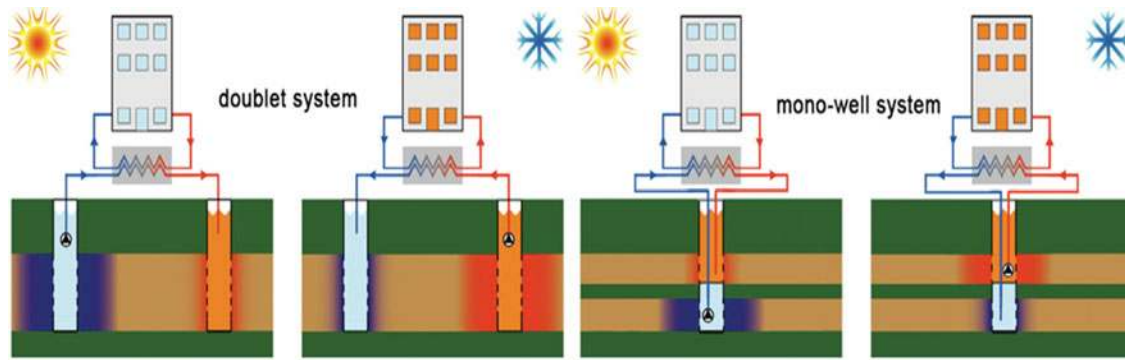
Fig. 11. Doublet and mono-well ATES systems (modified from [IF 2015]).

other previously mentioned storage systems have some limitations (Kranz and Frick 2013). However, ATES is highly dependent on the hydrological conditions of underground (Kousksou et al. 2014).

Recent studies has shown that the Building Energy Management System can assist to operate system in line with certain design and operating parameters; thereby increasing the COP of ATES. Kranz and Frick (2013) achieved an increase in COP for cooling from 3.6 to 7.8 over the period of time and concluded that COP can be even increased over 18. Miyata et al. (2007) has achieved 30% energy saving and increased COP from 3.02 to 5.04 by optimizing the operation of HVAC system with ATES. Two heat-pump-coupled ATES systems in thermal balance in the Klina hospital in Belgium, which leads to a COP 5.9 for heating and 26.1 for cooling (Vanhoudt et al. 2011).

Discussion

An LCC calculation with a period of 30 years is performed in which four building designs for the urban area are discussed: one references a building and three nZEB scenarios with energy saving measures, see Table 5. The focus will be on building installations, mainly the differences between the technologies. The calculation method is based on EU approach using Dutch principles (from previous studies) on cost optimality of energy saving measures.

Important parameters used are: inflation rate: 2.3%, discount rate: 6.4%, excluding CO_2 emission costs, no subsidies, energy tariffs including energy taxes, and value added tax. The reference building has an EP that applies to coming EPC demands (EPC = 0.7). The nZEB scenarios are well-insulated and built airtight, reducing energy demand. Installations used are ground source heat pumps, ATES, and large scale PV applications. An average EPC score of 0.16 (average primary energy demand 18.5 kWh/m²a) was obtained for the three scenarios.

Additional gains that have been included in the LCC calculation are increased productivity and reduced sick leave. Scientific research has proven that buildings with a healthy indoor climate (high ventilation rate) have increased productivity and reduced sick leave.

Results of the LCC calculation show, see Figure 11, that the nZEB scenarios are not cost-effective yet without additional gains. Average additional costs for the energy saving measures are 15 to 50 €/m² higher compared to the reference case, and 100 to 140 €/m² higher, for the financial analysis and macro-economic analysis, respectively. When additional gains are added, the total LCC cost drops significantly for both analysis (700 up to 1100 €/m²). The graphical representations (Figures 12 and 13) are shown in LCC' (€/m²) versus EPC demand for the case with and without additional gains.

The new strong demands for nZEB and a more sustainable built environment lead to a more complex design process. In line with the conclusion by Li et al. (2013), broadly speaking, nZEBs involve two design strategies: minimizing the need for energy use in buildings (especially for heating and cooling) through energy-efficient measures (EEMs; step 1 of the Trias Energetica; Figure 9), adopting renewable energy technologies (RETs; step 2 of the Trias Energetica; Figure 9), and other conventional technologies (step 3 of the Trias Energetica; Figure 9) to meet the remaining energy needs. EEMs include highly insulated building envelopes and highly efficient building services systems; RETs cover PV, solar thermal (solar water heaters), and heat pumps. The design teams of the recent completed buildings, mostly used an integrated design approach where there is cooperation between the different design teams. However, there is still a need for further improvement of the conceptual design process. Early decisions become more important than ever: the first week of the concept design for a new building can account for up to 80% of the cost commitment in a project (O'Sullivan and Keane 2005). This fact is even more pronounced for netZEBs, because of the tight interaction between user behavior, building, HVAC, and renewable energy systems (Biesbroeck et al. 2010). The increased complexity of building design inevitably calls for more design collaboration. A "new" or adapted design process called the morphological design approach could assist in the design teams with their immense complex design task. To fulfill the demand for nZEBs, there is a need for synergy between the architectural and engineering domain. To cope with this complexity architects need more support from specialized engineers. The different expertise of engineers must be used more effectively, especially in the conceptual design phase to

Table 5. Building installations for urban area scenarios.

	Urban area scenario office buildings			
	U_{ref}	U_1	U_2	U_3
EPC	0.70	0.20	0.14	0.15
Primary energy demand [kWh/(m²a)]	79.0	23.1	15.4	17.1
Installations				
Heating	Vertical GSHP with low temperature	Vertical GSHP with low temperature	ATES with low temperature	ATES with Road Collector with low temperature
Cooling	(30–35°C) floor heating	(30–35°C) floor heating	(30–35°C) floor heating	(30–35°C) floor heating
Hot tap water	Small electric boiler	Small electric boiler	Small electric boiler	Small electric boiler
Ventilation	Mechanical (balanced) with heat recovery (70%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)
Lighting system	Efficient lighting system (8 w/m²)	Efficient lighting system (8 w/m²)	Efficient lighting system (8 w/m²)	Efficient lighting system (8 w/m²)
Electricity generation	PV cells 170 m² (roof)	PV cells 770 m² (roof) 375 m² (façade)	PV cells 770 m² (roof) 375 m² (façade)	PV cells 770 m² (roof) 375 m² (façade)

reach for new solutions. This has consequences for the role of the engineers involved; they have to operate early in the conceptual building design process and act more as designers and less as traditional calculating engineers. As a consequence, engineers have to develop new skills (Zeiler 2014). This design collaboration could be assisted with another design approach, especially for new nZEB buildings. An approach where the architect is no longer is the one who leads the design process, but participates as a member of the team of architect(s) and engineers. In this design approach the focus is on applying a morphological support method (Zeiler 2013, 2014) in the conceptual design phase to increase the number of possible solution concepts considered to enlarge the solution space of the design teams. This achieves synergy between the different design disciplines instead of merely solving conflicts between them.
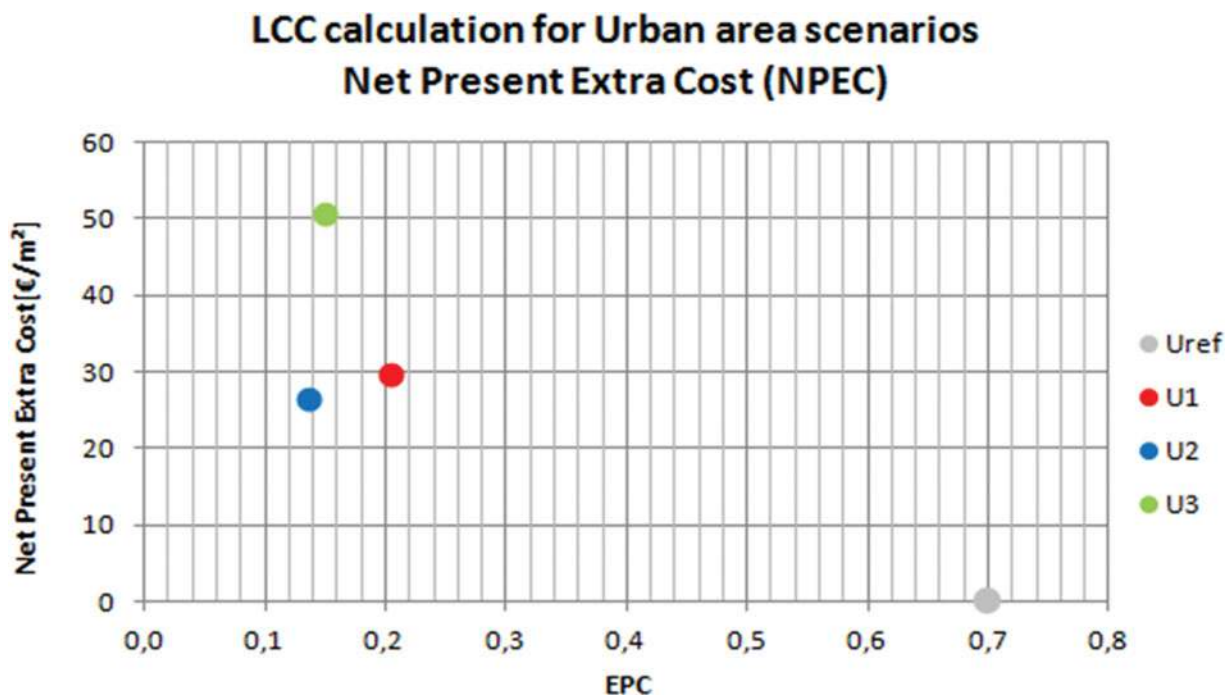
Fig. 12. Financial analysis without additional gains for urban area scenarios: office building.
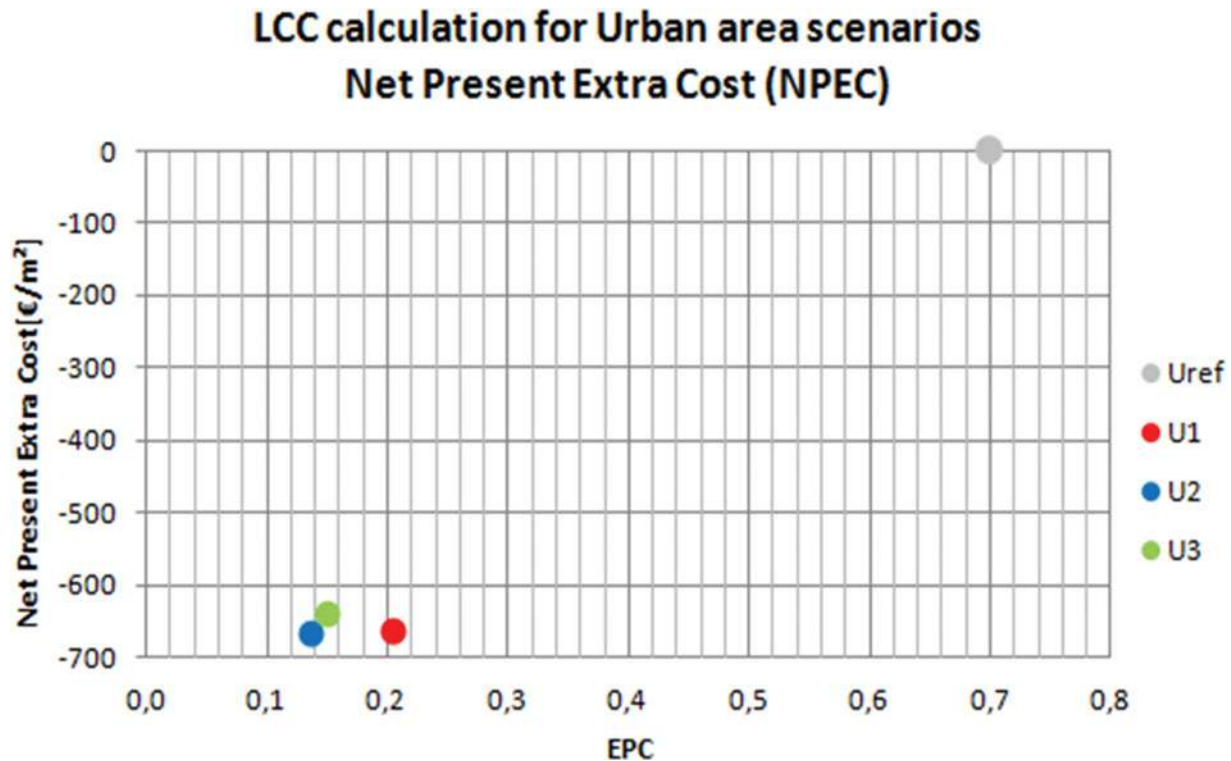
Fig. 13. Financial analysis with additional gains for urban area scenarios: office building.

Conclusions

This study on nZEBs in the Netherlands provides insight in the current situation of nZEBs and promising scenarios which are technically and financially feasible. The aim of this report was to give information on nZEB developments that will occur in the near future and what the consequences of these developments have for buildings, in particular for building services. Examples of nZEBs (offices) show the technical capabilities of energy saving measures: low EPC scores can already be achieved. Existing energy saving measures have been compared to measures applied to nZEBs: it clearly shows focus should be on energy demand reduction (insulation, glazing, and air tightness) and installations (heating/cooling system, mechanical ventilation with heat recovery, and application of large-scale PV).

In the Netherlands almost all sustainable offices applies geothermal ATES systems for seasonal heat and cold storage. By this, cooling and heating can be achieved with a relatively low primary energy consumption.

On basis of this study, in line with the study by dGmR 2013), a recommendation is made on EPC demands for offices. For a middle-sized office building it was possible to create nZEB designs with an average energy consumption of 20 kWh/(m²a) resulting in an EPC score of ~0.2. On basis of this study, an EPC of 0.2 for offices is recommended since it is technically feasible, and financially (taking into account additional gains) more attractive than an office building with EPC 0.7.

From the start of this research aims were set to understand the nZEB definition(s) for the new Dutch building stock

and to use this information during an integral design process. The ambitious targets for a new nearly zero built environment are currently rarely met. This is partly because low-energy buildings are typically seen as more costly than a conventional building. However, these buildings can be considered beneficial when, by a life cycle analysis, additional benefits for a higher renting value, PR, and better productiveness are taken into account. Additional gains—productivity and sick leave: the additional gains proved to reduce LCC of nZEB considerably. It should be noted that relatively simple methods have been applied to incorporate the gains into the LCC' calculation. The research used originated from studies which had comparisons between base cases with lower building performance (ventilation rate), than the base case for this study. For both additional gains (productivity and sick leave) values were used closest to the building performance of this study; however, a certain deviation existed. To gain more reliable results, more specialized calculations on increased productivity and reduced sick leave should be conducted for ventilation rate used in this study: $ACH_{ref} = 2 \text{ h}^{-1}$ and $ACH_{nZEB} = 3 \text{ h}^{-1}$. This may lead to lower additional gains; however, it is expected that the gains still lead to positive results (cost-effectiveness) for the nZEB scenarios.

Some of the additional gains were not incorporated in this research, although mentioned, are not taken into account in the LCC' calculation. Gains that should be further investigated are: PR value, higher renting value, and higher rest value. Further investigation on these subjects is necessary to define actual costs. It was concluded that owning and using an nZEB is more beneficial than of renting an nZEB to another party, because the additional gains of a higher renting price

is probably lower than the benefits of productivity and sick leave.

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