Abstract
Office buildings use relatively much energy compared to houses. Also their energy use increases whereas for houses it decreases. Therefore the design of nearly Zero Energy Buildings of our research was focused on offices. In the Netherlands almost all sustainable offices applies geothermal Aquifer Thermal Energy Storage systems for heat and cold storage. By this cooling can be achieved with a relatively low energy consumption, which was found in the primary energy demand diagrams of analyzed buildings, and therefore have a lower share of energy use compared to lightning, heating and ventilation. The main specifications of the recent nearly Zero Energy Buildings are given, as well is the main characteristics were put in charts.

Keywords – nZEB, ATES, low energy design

1. Introduction
People need buildings to protect them against the environmental conditions to be able to work and live. Building Services make it possible to provide comfort and an acceptable indoor Air Quality for building occupants. However, with 40% of the energy use within the developed world and 36% of the CO₂ emissions the built environment is one of the most important areas for sustainable development [1]. Overall the energy use of offices is nearly 40% of the total energy use of the built environment, so quite substantial.
In the Netherlands offices have a relatively high energy consumption and the office buildings use in total around 225 PJ/year, compared to around 370 PJ/year for households, see Fig. 1[13]. More important, the energy consumption of office buildings are increasing slightly, see Fig. 1, despite the 2020 targets set by the EU. This is due to higher comfort needs and the use of more conditioning systems with cooling.
To reduce this high energy demand and pollution of greenhouse gasses the Energy Performance of Building Directive (EPBD) came in 2010 with plans for the European Union member states. One of these plans, as written in article 2 and 9 EPBD, is to reduce the energy demand and greenhouse gasses of new buildings. Building performance in the Netherlands is expressed in Energy Performance Coefficient (EPC): a policy tool according to Dutch standard NEN 7120 [11] providing a calculation method for building energy performance. To determine the EPC the key characteristics of the building (dimensions, level of insulation of roof/walls/floor, type of materials and window including frame etc.) and installations (heating, cooling, hot water, ventilation, and lighting) are taken into account [4].

2. From EPC towards nZEB

The EPC calculation is the basis for the building’s energy performance certificates. The EPC gives an indication of the primary energy demand as designed; however the actual demand is also largely dependent of the actual built situation, maintenance, operation and occupant behaviour. Implementation of the EPC regulation is quite successful. During the period from 2008 until the end of 2012 over 2.4 million residential energy performance certificates were issued, covering more than 30% of the residential building stock. In the non-residential sector, a total of 15,000 certificates were issued in the same period, mainly for offices, retail and shops or shopping malls [6].

Table 1 shows an overview of EPC requirements for Dutch buildings for both the residential and non-residential sector. Over the years, the EPC demand
for residential buildings has been tightened from 1.4 at the start in 1995, to 0.6 from January 2011 onwards. Building industry has agreed with the Dutch government on a further tightening of the requirements in the near future, in order to move towards nZEB in 2018 (governmental buildings) and 2020 (all other buildings). The EPC requirement for the residential sector is scheduled to decrease to 0.4 in 2015. For the non-residential sector, this requirement is scheduled to be lessened by 50% by 2017 compared to the EPC requirements of 2007 [6]

Table 1 Current and future EPC requirements for Dutch buildings. [4,5,6,7]

<table>
<thead>
<tr>
<th></th>
<th>Current policy</th>
<th>2015</th>
<th>2017 (1)(2)</th>
<th>Future policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offices</td>
<td>0.6</td>
<td>0.4</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Health, clinical</td>
<td>1.1</td>
<td></td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Health, non-clinical</td>
<td>2.6</td>
<td></td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Educational</td>
<td>1.0</td>
<td></td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Retail</td>
<td>1.3</td>
<td></td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Sports</td>
<td>2.6</td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
</tbody>
</table>

(1) According to the National Plan to promote nearly Zero Energy Buildings in the Netherlands
(2) 50% decreased primary energy consumption compared to 2007 for governmental buildings

The building Performance Institute Europe (BPIE [2]) provides a useful diagram, see fig. 2, which uses cost-optimization as the main driver for the ‘nearly’ approach and the balance with primary energy, see Fig. 3 [3].

Fig. 2 Principles for sustainable nZEB in the EU [2]
3. The Dutch present nZEB status

A review of built sustainable buildings in the Netherlands reveals that the nZEB are feasible and examples are already there [8]. But for the greenhouse gas emission target of 3 kg/CO$_2$·m$^2$ it looks ambitious. More realistic approaches proposed a design condition of 3 to 8 kg/CO$_2$·m$^2$, which could be a little easier to reach. 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 [14] 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/CO$_2$/m$^2$, which is almost 17 times as much as the BPIE [1] states for an nZEB.

In an inspiration book about 15 sustainable offices [8] only one building was found which falls between the advised boundary conditions (AIDA) of an nZEB, see Fig. 4. 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 photovoltaic-energy; there are plans to extent the installed PV-capacity, this could transform it into an energy-neutral or even energy-plus building. The building has an Aquifer Thermal Energy Storage (ATES) system (with 2 cold and 2 warm, underground wells at a depth of 80m$^1$) and a high temperature underground thermal energy storage system (40–45 °C at a depth of 300m$^1$). Heat is mainly generated with 478m$^2$ 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 8kg CO$_2$/m$^2$. The biggest fraction of the primary energy use goes to lightning and then to heating and ventilation, see Fig. 5.

Fig. 4 Comparison primary energy demand ‘sustainable buildings [8]

Fig. 5 Primary Energy demand of the Dutch sustainable-office NIOO-KNAW, of an average Dutch office building [8]
4. A new approach to achieve nZEB

Traditionally, the potential for nZEBs in the Netherlands was mainly determined by the possible applications of building energy reduction measures according to the Trias Energetica method, see Fig. 6. An adapted version of the Trias Energetica method could be used in the future adding the integration of user behavior as well as energy exchange and storage systems (smart grids), see figure 5. Especially these possibilities become crucially important for nZEB because of the intermittent characteristics of most renewable energy sources. 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, ICT data centers, swimming pools or other sports facilities like ice rinks).

Fig. 6 The Trias Energetica method and the Five step method [9]

Especially the application of Aquifer Thermal Energy Systems (ATES) offers a large potential in the Netherlands and as a result almost all sustainable offices applies geothermal ATES systems for seasonal heat and cold storage. 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 approx. 14 °C) is pumped back to the building. The water is
cooled to approx. 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. The storage wells can be located horizontally or vertically spaced to each other (Fig. 7). 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.

![Fig. 7 Doublet and mono-well ATES systems (modified from [10])](image)

The ATES reaches an operational Coefficient of Performance (COP) of around 10 compares to a regular (compression based) cooling system reaching a COP of around 4, standard NEN 7120 [11]. 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, standard NEN 7120 [11]. However, assuming an average Dutch electricity generation efficiency of 42% [12], this is still a 60% higher efficiency than natural gas boilers and is required to provide the cold water storage supply.

The Dutch soil structure is particularly suitable for ATES application: the groundwater level is relatively close to the ground level (to avoid expensive deep drilling) and 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. 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.

5. Overview recent nZEB development
In 2009 the Dutch government started their so called UKP NESK program to stimulate innovation for energy neutral buildings. UKP means unique chances projects and NESK means 'Towards energy neutral schools and offices’ (Naar Energieneutrale Scholen en Kantoren). 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 2. 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. This resulted already in a second generation of nZEB which are listed in table 2.

Table 2 Comparison of the first series of nZEB office buildings in the Netherlands.

<table>
<thead>
<tr>
<th>Year</th>
<th>Eneco office (Rotterdam)</th>
<th>NIOO/KNAW (Wageningen)</th>
<th>Villa Flora (Venlo)</th>
<th>TNT office (Hoofddorp)</th>
<th>CBW Mitex (Zeist)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEATING</td>
<td>Electric heat pump &amp; ATES with district heating</td>
<td>Electric heat pump &amp; ATES</td>
<td>Bio CHP, Electric heat pump &amp; ATES</td>
<td>Bio CHP, Electric heat pump &amp; ATES</td>
<td>Bio CHP, Electric heat pump &amp; ATES</td>
</tr>
<tr>
<td>COOLING</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
</tr>
<tr>
<td>PV system</td>
<td>1140 m²</td>
<td></td>
<td></td>
<td></td>
<td>650 m²</td>
</tr>
<tr>
<td><strong>EPC</strong></td>
<td>0.72</td>
<td>0.40</td>
<td>0.38</td>
<td>0.67</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 3 Comparison of 2nd series of nZEB office buildings in the Netherlands.

<table>
<thead>
<tr>
<th>Year</th>
<th>Enexis office (Venlo)</th>
<th>Venco Campus (Eersel)</th>
<th>Enexis (Venlo)</th>
<th>Hitachi data (Zaltbommel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEATING</td>
<td>Electric heat pump &amp; ATES with boiler (HR107)</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Bio CHP, Electric heat pump &amp; ATES</td>
</tr>
<tr>
<td>COOLING</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
<td>Electric heat pump &amp; ATES</td>
</tr>
<tr>
<td>PV system</td>
<td>2100 m²</td>
<td>5700 m²</td>
<td>2100 m²</td>
<td>1000 m²</td>
</tr>
<tr>
<td><strong>EPC</strong></td>
<td>0.00</td>
<td>-0.298</td>
<td>-0.14</td>
<td>-0.83</td>
</tr>
</tbody>
</table>
Heating and cooling is provided in all projects by the combination of ATES with a heat pump. Floor heating of concrete core activation is used a release system and by applying recovery wheel within the ventilation system, heat is regenerated to the building. Furthermore a bypass ensures no overheating occurs during the summer. Other aspects that make these buildings very energy efficient are: climate ceilings, energy efficient lighting, daylight control and presence detection.

6. Conclusions

So an important aspect for nZEBs is the optimal use of the surrounding energy infrastructure. Future energy infrastructure will be connected on a local level, with an integrated smart grid (energy exchange between buildings). The energy infrastructure has to be able adapt to changing conditions such as; changing building functions during the lifetime of the building, future extension of buildings, etc. Fig. 8 shows the vision on energy infrastructure on nZEBs in the built environment [4]. In current situation single buildings are connected to energy generating infrastructure (red circle) and Aquifer Long Term Energy Storage (ATES) systems (blue circle). In future the buildings will be connected to each other to enable energy exchange as well as to centralized energy storage systems such as ATES on neighborhood level to ensure a stable energy network.

![Fig. 8 Current and future energy infrastructure in the built environment [9]](image_url)

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. In the Netherlands almost all sustainable offices apply geothermal ATES systems for seasonal heat and cold storage. By this cooling and heating can be achieved with a relatively low primary energy consumption. Therefore it is almost a prerequisite for Dutch nZEB.

References