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Building Concepts for a mid-century energy-neutral society

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ABSTRACT: In this paper an analysis is presented of the building stock development from now to 2050 and building concepts and scenarios for a mid-century energy-neutral built environment in the Netherlands. The analysis deals with new and existing residential and non-residential buildings and distinguishes different aspects of the energy balance; space heating and cooling, domestic hot water and electricity consumption. An analysis is made of the mix of measures which is needed to reach net energy-neutrality in the built environment in 2050. With the term 'net energy-neutrality', the overall annual energy-usage of the complete building stock, including built environment related systems such as streets within cities is meant, incorporating energy exchange with the industry and transport sectors.
Based on the building stock analysis and their energy scenario's, three building concepts are sketched with ambition levels needed for an energy-neutral Dutch building sector in 2050. The defining characteristics of these building concepts are their energy balance and also their impact on health, comfort and the integral living expenses. Modelling energy flows in the building is part of this evaluation.

Keywords: energy-neutral, building stock development, building concepts, comfort

1. INTRODUCTION

Our world is strongly on the move. The climate changes. More and more uncertainty exists concerning the energy supply. The discussion is no longer about the need to contemplate the future of energy supplies but about the way we can meet the future energy demand in a sustainable way. Both national and international policies are developed in the climate field and people devote themselves to energy transition.

In the Netherlands more than one third of the energy is used in the built environment. Insulation of buildings, more efficient comfort installations and local generation of sustainable energy have strongly improved the energy performance of buildings in the previous decades. The potential for even better energy performance however has still not been exhausted yet. The urgency to bring all measures for improvement of the energy performance into action, and thereby connecting to nationally and internationally pursued policy, increases.

The Dutch research institutes TNO and ECN have started the strategic cooperation *Building Future* (BF) in the field of energy in the built environment in order to jointly give an impulse to this transition. Both institutes believe that by the middle of this century energy neutrality in the built environment can be reached, provided that the developments to this end are tackled energetically.

Insight in development of new and existing residential and non-residential buildings is essential to aim for an energy-neutral built environment. From trends [1] on the increase of buildings in the housing stock, the amount of newly developed houses each year and the demolition rate, a development of the composition of the housing stock can be extrapolated. This development from 2004 (red bars) to 2050 (green bars) is shown in Figure 1.

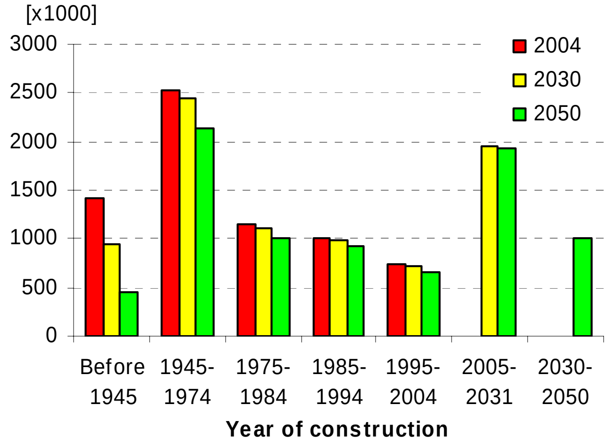

Figure 1. Development of the composition of the Dutch housing stock.

The average age of the housing stock as a whole will increase from approximately 40 years now to 60 years in 2050. Figure 1 implicates that the major part of the energy consumption will come from new dwellings built between 2005-2050 and the dwellings constructed in the period 1945-1974, which is the segment currently up for renovation.

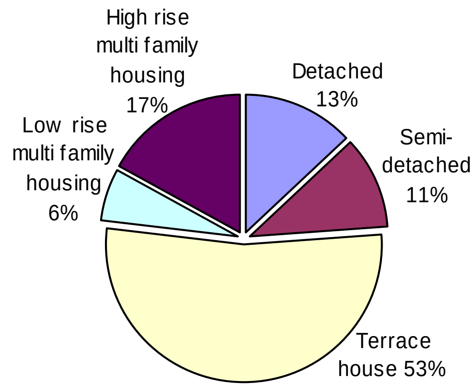

Figure 2. Distribution of types of dwellings in Dutch housing stock.

The current distribution of types of dwellings in the housing stock is illustrated in Figure 2.

The number of houses in which renovation (now approximately 150.000 a year), large maintenance (now approximately 300,000 a year) and installation replacement (now approximately 450,000 a year) will take place, will increase slightly during the coming years with up to 20 %.

2. ENERGY IN THE BUILT ENVIRONMENT

2.1 Business as usual

Future energy consumption of the built environment mainly depends on the development of the building stock, but also on global and national developments, such as climate change, national turnover and policy-effectiveness. The building related modifications influencing energy consumption involve construction of new dwellings, demolition, renovation, extensive maintenance and installation replacement. The change in energy consumption in the housing stock associated with these developments are listed in Table I, along with expected change in electricity consumption associated with use of household appliances (HHA).

Table I: Impact of developments in residential building sector on gas and electricity consumption in % per year compared to the reference year 2000: 'Business as Usual'.

Mutation (%)	Electricity (%)	Gas
- New buildings[1]	-5	-5[2]
- Renovation	-15	-20[2]
- Maintenance	-5	-20[2]
- Installation replacement	-6	-10[2]
- HHA		+1

Taking all these developments into account, future energy consumption according to the 'Business As Usual' scenario can be outlined [1]. Figure 3 illustrates that the expected total primary energy consumption in the building sector remains approximately 1000 PJ_p. Two significant trends contribute to this stabilization. Due to improved building insulation and more efficient comfort installations, gas consumption is expected to decrease. On the other hand, electricity consumption increases. Domestic electricity consumption is about to increase mainly due to increasing cooling needs and increased use from HHA. A growing number of ICT related applications contribute to increasing electricity consumption in the non-residential sector.

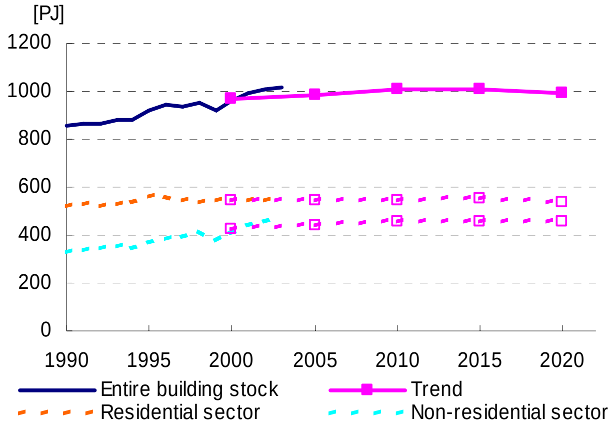

Figure 3. Total primary energy consumption in the building sector according to the 'Business As Usual' scenario.

2.2 Building Future scenario

The research program of *Building Future* (BF) aims at reducing the total net energy usage of the built environment to energy-neutrality around the middle of the century. To this end several technological and non-technological developments have to be undertaken linked to the building stock improvement moments.

To study the potential of measures, a model has been developed. With this model the effect of several separate measures is examined related to the different improvement moments:

- Replacement of heating installations (every 15 years) including compact heat storage and thus reducing the energy for heating and domestic hot water (DHW), by 50% per year overall, will result in a reduction of 140 PJ/year by 2050.
- If from 2015 onwards all new to build dwellings would be energy-neutral a reduction of 60 PJ would result by 2050.
- Even if from 2015 onwards the introduction of net energy producing

[1] Annual improvement of new to build dwellings
[2] Annual development of building related electricity consumption

dwellings would be taken on (app. 4.5 GJ/year/building), a maximum reduction of 185 PJ/year could result by 2050.

- On the other hand, when all effort is directed towards renovation, for instance by implementing renovation packages that will reduce the demand for heat and DHW by a factor 4 and additionally in-tegrate Renewable Energy (RE) from the sun in the building, the total reduc-tion will not exceed 150 PJ/year by 2050.
- Reduction of energy used by HHA by 2% per year from 2015 onwards, might result in a total reduction of 200 PJ/year by 2050.

The above findings illustrate that, if an energy neutral built environment is to be reached, focus on only one of the building stock developments will not suffice; all the building stock improvement moments have to be used and a reduction of the user-related energy (HHA) should be accomplished as well. The required combi-nation of measures (which are interrelated) for the residential sector is listed in table II.

Table II: Impact of developments in housing sector on energy consumption [%] compared to the original situation according to BF scenario.

Mutation (%) RE (kWh/a)		Heat (%)	Elec.
- New buildings	-40		-4000
- Renovation	-75		-1700
- Maintenance	-15	-20	-
- Installation replacement	-50	-50	-
- HHA	-	-2	-

On top of this, the total energy consumption of the non-residential sector should decrease from 0% in 2010 up to 5% per year in 2025. Most of the targets listed, albeit ambitious, can be achieved with introduction of the required building concepts around 2015, using existing technologies and technologies currently under development.

If all of the abovementioned measures are set in place the resulting development of the net energy usage of the built environment is depicted in Figure 4. Table II and Figure 4 illustrate that building related measures (for new to build dwellings and the existing stock) are not sufficient to reach energy neutrality. Also reduction of user related energy (HHA) and measures on district level (yellow line) should be introduced.

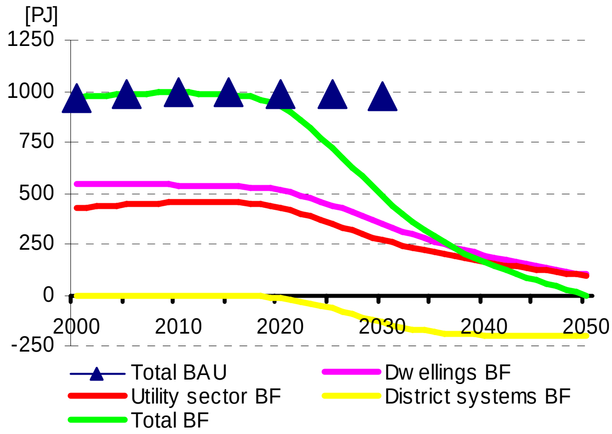

Figure 4. Development of net energy usage.

3. CONCEPTS FOR THE FUTURE

In the previous section it is shown that in order to reach an energy-neutral built environment in the Netherlands around mid-century, there is a demand for building concepts with a higher (energy) ambition level than currently available. These ambition levels are the setpoint for a number of building concepts for residential dwellings and non-residential buildings and are based on expected availability of technology in the year 2010, with estimated payback times of the complete concepts of approximately 15 years. A short description is given of two residential dwellings and one office building concept. In all concepts a strategy is used in which as a first step the energy demand is reduced as much as possible, in line with PassivHaus targets [2]. The second step is to fulfil the need for energy wherever possible with renewable energy sources and, thirdly, using fossil fuels if still needed in an energy efficient way. Both residential dwelling concepts discussed below have the following measures in common:

- Increasing the insulation levels of walls, floor and roof to Rc=7.5. Windows are replaced by triple glazing U=0.6.
- Improving the air tightness to 0.6 air changes/hour at 50 Pa.
- Heat recovery from ventilation air by using either a central balanced system or decentralised solutions like a facade integrated HVAC or a window-frame integrated system (new development)
- Application of external shading to prevent overheating.

3.1 Residential renovation concept

As a reference case a typical Dutch terraced house of the late sixties is selected, since the major part of the housing stock currently up for renovation resembles the building characteristics of this type (see Figure 1 and Figure 2). The aim is to bring back the total energy demand for gas and electricity 'on the meter' to one quarter of the existing energy end-use before renovation. This means that besides building related energy (heating, domestic hot water, ventilation, lighting, etc.) also building related measures to reduce energy consumption of HHA have to be taken into account. In addition to the reduction of the energy demand for space heating, described above, the following measures are incorporated:

- Heat recovery for DHW from the (renewed) shower
- Installation of intelligent sockets designed to minimise standby losses of HHA
- Heat recovery and storage connected to water distribution system of dish water and washing machine
- Replacement of standard boiler by a micro-Combined-Heating-Cooling-Power-generator micro-CHCP operating in combination with a solar collector.

The energy usage of this concept before and after renovation are illustrated in Figure 5.

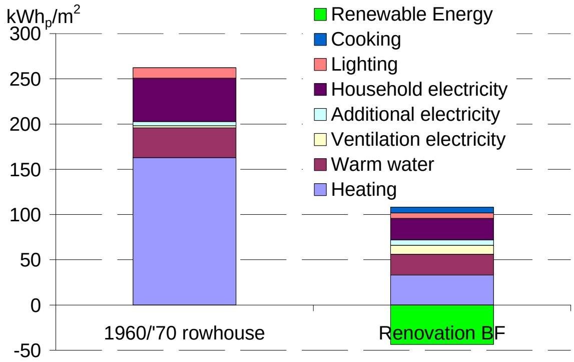

Figure 5. Energy usage before and after renovation.

3.2 Concept for newly built dwellings

A general feature of the generated concepts for new buildings is that they are at least energy-neutral on a yearly base and net energy producing on a larger district level. This means the buildings themselves will serve as energy-generators, in line with the ambition levels presented in the previous paragraph. Here, a short description is given of the measures to transform a standard (new to built) dwelling into an energy-generating dwelling in addition to the Passivhaus measures, described above:

- Active (top)cooling is available with a reversible small size heat pump
- Compact chemical heat storage techniques are used for storage of DHW as well as space heating
- Solar PVT collectors are used for heat and electricity generation. Alternatively, vacuum tube collectors can be used, that produce electricity in a second step, using an organic rankine cycle machine connected to a (low temperature) district heating system.

In Figure 6 the energy needs of a standard Dutch (new) dwelling [3] and the dwelling of the Building Future concept are compared. For this case the installation of 4000 kWh renewable energy is assumed, corresponding to about 90 kWh/(m^2 year).

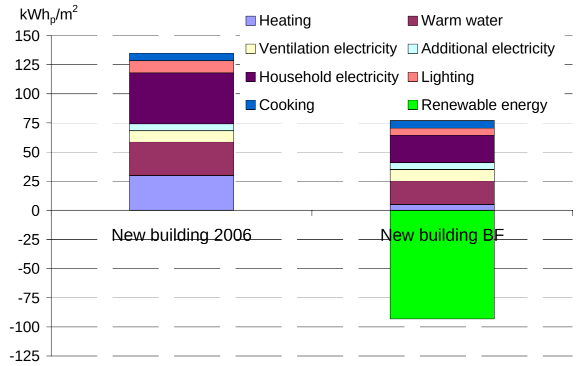

Figure 6. Energy needs of a standard new dwelling and a BF concept dwelling.

3.3 Thermal comfort

Simulations with TRNSYS show that for both presented new and renovated buildings the temperatures in summer and winter are very comfortable. In summer external shading and night cooling should be used to avoid overheating. The amount of overheating hours (> 25 ^{0}C) can thus be reduced to very acceptable levels.

3.4 Costs and financing

The building concepts are based on payback times of approximately 15 years. The aim is to have an equal burden of living costs before and after renovation. Therefore extra costs for building measures and energy generation should in principle be paid from the lower energy-bills and the improved comfort level. Taking into account a moderate increase of the energy prices, the estimated savings amount to more than € 1,400.- /year for the renovation concept. Since costs and savings do not take place at the same moment in time, new financing schemes are called for, for instance based on integral living expenses.

3.3 Renovation concept office building

Office buildings represent about 20% of the energy consumption in the non-residential sector (88PJ$_p$ total). A renovation concept is developed for low-rise office buildings, built in the period from 1960 to 1980. The concept not only aims at reducing building and user related energy consumption, but also at increasing productivity by improving indoor comfort.

In contrast to the domestic building sector, electricity consumption typically dominates in office buildings (69%). Especially lighting and ICT related applications have significant contributions. Gas is primarily used for space heating; the demand for domestic hot water is negligible. In order to reduce energy consumption, the following measures are listed:

- Insulation according to Passive house standards: Increasing insulation levels of walls, floor and roof (from R_c=0.80 to R_c=7.0) and replacing windows
- Occupant and daylight dependant lighting systems with HF lighting
- Energy efficient ICT and building related office equipment
- Heat recovery from ventilation air using either a central balanced system or local facade-integrated systems
- Photo Voltaic Thermal (PVT) solar system for simultaneous sustainable generation of electricity and heat
- Organic Rankine Cycle (ORC) technology in combination with vacuum tube collectors for sustainable generation of electricity and heat. Excess heat can be transferred to a low temperature district heating system
- Sorption cooling using the ORC as thermal energy input
- Amorphous Photo Voltaic cells for additional solar generated electricity

Implementing the above listed measures result in a 76% reduction of primary energy consumption, as illustrated in Figure 7.

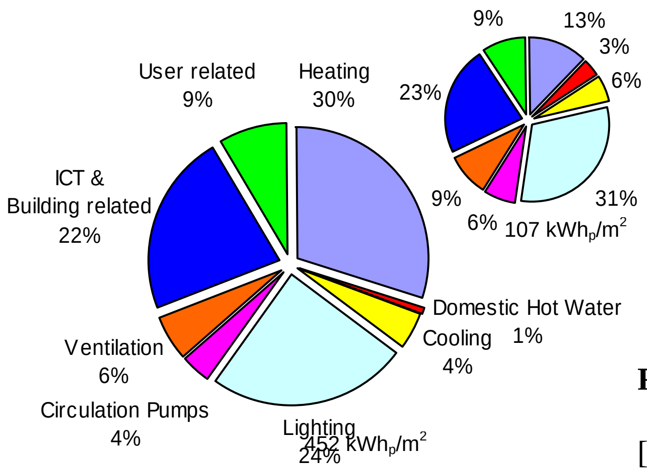

Figure 7. Impact of renovation measures on existing office building.

4. CONCLUSIONS

The developments concerning the built environment indicate that in a business as usual scenario, the energy usage will not decrease although a great potential for reduction exists. This potential can only be achieved by bringing about a transition to a sustainable energy system in the built environment, borne by all responsible parties.

From the BF scenario, associated with this transition, it can be deduced that all available measures for improvement should be used. This implies making best practice (such as Passivhaus measures), common practice and developing necessary technologies for essential concepts such as energy generating new to build dwellings and factor 4 renovation concepts.

Potentially successful concepts incorporate technologies for building related and user related energy reduction as well as integration of renewable energy technology.

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