Building concepts for a transition towards energy neutrality in 2050

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ABSTRACT: In this paper building concepts for the near future are described which enable the transition towards a net energy neutral building sector in the Netherlands by the year 2050. With 'net energy neutrality' is meant that, on a yearly basis, the total energy consumption in the built environment is compensated by local renewable energy production e.g. by using solar thermal (T), photovoltaic (PV), PVT and/or wind. A previous study concerning the feasibility of a 'net energy neutral built environment by 2050' [1] set the energetic ambitions for the building concepts to be developed.

This resulted in different concepts for residential buildings and for office-buildings. The building concepts are based on passive house technology to minimise the heating and cooling demand, and make optimal use of active and passive solar energy. Concepts for new to build domestic buildings are in fact energy producing to compensate for the remaining energy demand of existing, renovated dwellings. In all concepts the 'trias energetica' or 'energy pyramid' served as a general guideline, striving for minimisation of energy demand, maximal usage of renewable energy and usage of fossil fuels as efficiently as possible.

Different full roof integrated options for using solar energy (PV, T or PVT) with variable storage options have been compared by making simulations with a dynamic simulation programme, to gain insight on their impact on energy, building engineering and economic impact. Also different possibilities for installations to fulfil the heating demand for the space heating and DHW demand are described. For residential buildings (renovation, new built) and office buildings, the resulting primary energy profiles (for space heating and cooling, domestic hot water, lighting, ventilation and household appliances) to reach a energy neutral built environment in 2050, are given.

1. INTRODUCTION

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 production 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. 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 Dutch built environment can be reached, provided that the developments to this end are tackled energetically.

2. SCENARIO ANALYSIS

A scenario analysis concerning the feasibility of a 'net energy neutral built environment by 2050' set the energetic ambitions for the building concepts to be developed [1]. To study the effect of plausible technological breakthroughs, a scenario analysis tool is used. As inputs for the tool the current and projected development of the number of buildings and the present energy usage is needed.

2.1. Development of built environment

The projected development of the number of buildings, resulting from trends in the number of new residential buildings build every year and the number of residential buildings demolished. Two possible scenarios were considered: The Strong Europe (SE) and Global Economy (GE) scenarios. The scenarios have a different outcome with respect to the development of the number of residential buildings as illustrated in Figure 1.

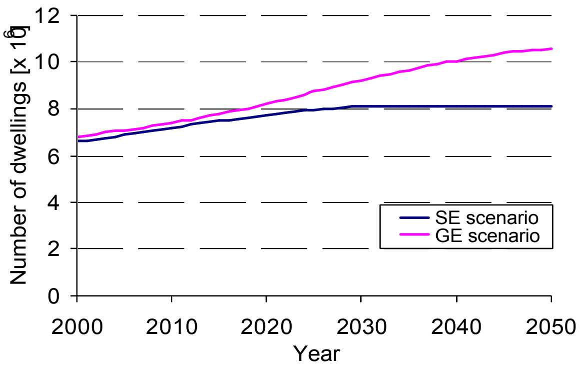

Figure 1. Development of number of residential buildings.

In this study the development as depicted by the SE scenario is used as reference in the model, and will in the remainder of this paper be referred to as Business as Usual (BaU). 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 %.

2.2. Current energy consumption

The energy consumption profile of the Dutch built environment in 2000 as illustrated in Figure 2. The figure illustrates the distinct difference between residential and non-residential buildings: in residential buildings 65% of the total primary energy is used for heat, whereas in the non-residential sector electricity is dominant (52%).

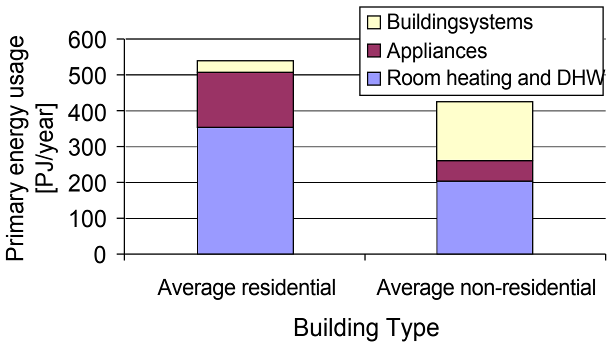

Figure 2. Energy consumption profile for the built environment in 2000

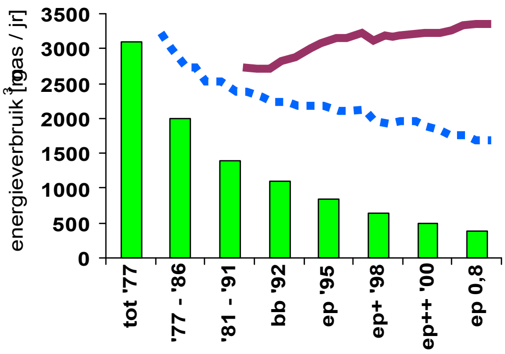

Figure 3. Energy usage development from 1990-2008

In the last decades the space heating demand for typical new built terraced houses was successfully decreased from 3000 m^3 in 1990 to 500 m^3 natural gas nowadays (2008). However the amount of electricity used for household appliances has risen in the same time, as illustrated in Figure 3.

3. BUSINESS AS USUAL AND BUILDING FUTURE SCENARIO

In a scenario study carried out in 2006 [1] the impact of different plausible technological breakthroughs on the energy usage in the Dutch built environment in the period from 2000-2050 is assessed and compared to a 'bussiness as usual' (BaU) scenario.

3.1. Business as usual

The outcome from existing scenario studies based upon the work of [1] and [3] was used as a reference for the BaU scenario. This approach has the advantage that its results can serve as a beacon for policy makers and market developers. But it also provides a foundation for a long term R&D agenda.

Future energy consumption of the built environment mainly depends, amongst others, on the development of the building stock. The building related modifications influencing energy consumption involve construction of new residential buildings, demolition, renovation, extensive maintenance and installation replacement.

The change in energy consumption in the housing stock associated with these developments, derived for the BaU scenario, are listed in Table I, along with the expected change in electricity consumption per year associated with use of household appliances (HHA).

Table I: Developments in residential building sector on gas and electricity consumption in % compared to reference year 2000: 'Business as Usuall'.

Mutation	Gas (%)	Electricity (%)
- New buildings[1]	-5/year	+1,5/year[1]
- Renovation	-17	-20[2]
- Maintenance	-8	-20[2]
- Installation replacement	-8	-10[2]
- HHA	+0,8[2]/year	
- Renewable Energy (RE):	Implicit	

The expected total primary energy consumption in the building sector, resulting from the changes associated with the BaU scenario, remains unchanged at approximately 1000 PJp.

3.2. Potential for energy neutrality

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. The required combination of developments (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	Heat (%)	Elec. (%)	RE (kWh/a)
- New buildings	-40/year	-	4000
- Renovation	-75	-20	2000
- Maintenance	-15	-20	-
- Installation replacement	-50	-50	-
- HHA	-	-2	-

The technological and non-technological measures that could meet the above listed developments:

- 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% overall through system replacement.
- Introduction of net energy producing residential buildings from 2015 onwards (starting at app. 4.5 GJ/year/building).
- Implementation of renovation packages that will reduce the demand for heat and DHW by a factor 4 and additionally integrate Renewable Energy (RE) from the sun in the building envelop.
- Reduction of energy used by HHA by 2% per year from 2015 onwards.

1 Development of building related electricity consumption due to mutation

2 Average value over the period 2000-2050. In the model the trends between several key years as taken from [1] are used.

This analysis shows 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.

On top of these measures, the total energy consumption of the non-residential sector should decrease from 0% in 2010 up to 5% per year in 2025. This decrease in fact implies the same trend in energy consumption as for the residential sector. 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 inFigure 4. Table II and Figure 4 illustrate that building related measures (for new to build residential buildings and the existing stock) are not sufficient to reach energy neutrality. Also reduction of user related energy (HHA) and measures on district level (bottom line) should be introduced.

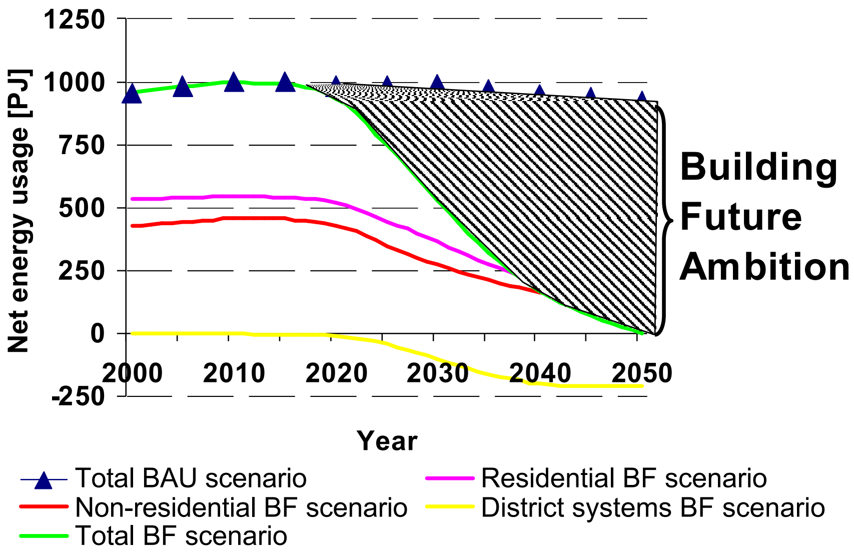

Figure 4. Development of net energy usage.

3.3. CO_2 and economic implications

The effect of the Building Future scenario in terms of CO_2 emission directly related to residential buildings and user related electricity, is a reduction from 31.4 Mton in 2000 to 5.5 Mton in 2050. This implies a 83% reduction of building related CO_2 reduction for the residential sector with respect to the reference year 2000. With respect to Business as Usual in 2050 it implies a 2.5 times higher reduction of Mton CO_2.

To evaluate economic effects for the residential sector, energy price developments were incorporated, corrected for inflation. Three scenario's were compared:

1. The energy price developments associated with the SE scenario. The effect on consumer prices for electricity would be 1.6% per year until 2020 and app. 1.3% per year from 2020 onwards. The effect on consumer gas price would be an increase of 0,8% until 2020 and an increase of 0,6% per year from 2020 onwards.
2. An overall 3% increase of consumer price for electricity and gas per year.
3. Continuation of the consumer energy-price developments of the last 6 years in the Netherlands, derived from statistical data gathered by CBS. These imply an increase of the consumer electricity price of 2.8% per year and an increase of the consumer gas price of 7.7% per year.

Using these energy-price developments it is calculated that the combined measures for the residential buildings result in savings on the energy bill between 2006 and 2050 of app. €23,000.- for SE, €44,000.- for the 3% increase and €100,000.,- per building. The Net Present Value than amounts to app. €12,000.- €22,000.- and €47,000.- per building respectively.

4. FUTURE BUILDING CONCEPTS APROACH

In the previous sections 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 set point for a number of building concepts for residential buildings 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 buildings and one office building renovation concept. In all concepts the strategy of the 'Trias Energetica' (see figure 5) is used in which as a first step the energy demand is reduced as much as possible, in line with Passivehouse targets [5]. 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.

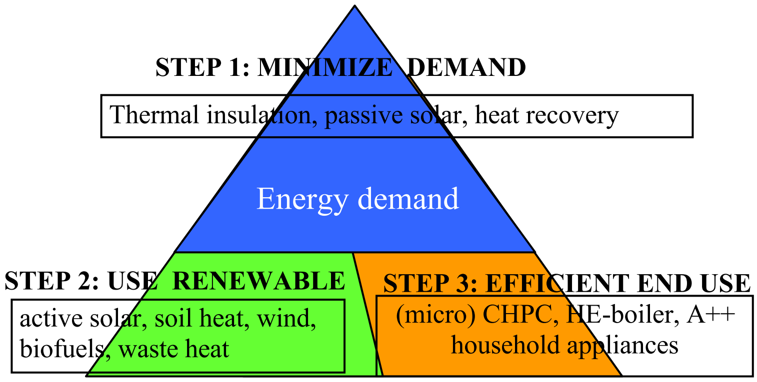

Figure 5. Energy pyramid or Trias Energetica

Both residential building and office concepts as described below have the following measures in common:

1. Increasing the insulation levels of walls, floor and roof to R_c=7.5 m2.K/W. Windows are replaced by triple glazing U=0.6 W/m2.K.
2. Improving the air tightness to 0.6 air changes/hour at 50 Pa.
3. 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)
4. Application of external shading to prevent overheating.

5. RESIDENTIAL BUILDING FUTURE RENOVATION CONCEPTS

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. The aim of BF 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, as 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

For the efficient provision of remaining energy demand, based on natural gas, possible solutions are:

- Gasfired sorption heatpump for the concept 'Heating and cooling with the sun'. Reversible heatpump in combination with a large solar collector system and PV.
- Replacement of a standard boiler by a gasfired micro-Combined-Heating-Cooling-Power-generator (micro-CHCP) for the concept 'Home Power Plant', operating in combination with a PVT roof.

The resulting energy usage of the residential renovation concept before and after renovation is illustrated in Figure 6.

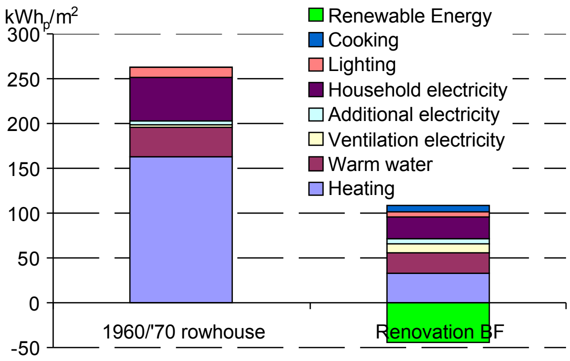

Figure 6. Energy usage before and after renovation.

Figure 7. Typical sixties Dutch terraced house

6. RESIDENTIAL BUILDING FUTURE NEW BUILDING CONCEPTS

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.

In addition to the reduction of the energy demand for space heating, and the reduction of household appliances as described in the renovation case, the following concepts for an efficient provision of remaining (fossil) end energy demand are given:

- Electrical heat pump for the 'All electric' concept. In combination with a small solar collector (m^2) and large PV system.
- HE gas fired boiler for the 'Local energy storage' concept. In combination with large thermal solar system (m^2) and 8m^3 storage.
- Combined Heat and Power (CHP) in combination with a thermal system for district heating (Full roof vacuum tubes) for the 'Renewable District Heating" concept.

In Figure 8 the energy needs of a standard Dutch (new) residential building [6] and the residential building of the Building Future concept are compared. In this case the installation of 4000 kWh renewable energy is assumed, corresponding to about 90 kWh/(m^2 year).

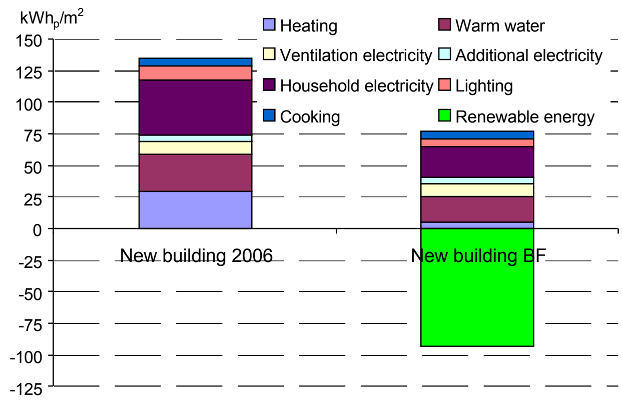

Figure 8. Energy needs of a standard new residential building and a BF concept residential building.

Figure 9. Impression of a dwelling with the roof as energy generator' [source: WAELS]

7. ROOF POTENTIAL FOR SOLAR ENERGY

For dwellings the most suitable location for generating renewable energy is the roof. For a typical Dutch terraced house the surface which can be used is assumed approximately 40 m^2 for new built and 30 m^2 for renovation dwellings.

For these roof areas the energy generation potential is simulated for combinations of photovoltaic modules (PV), solar thermal (T) and combined thermal and photovoltaic modules (PVT). Apart from 'main stream' solar collectors and PV-panels, the last couple of years ECN has put a considerable R&D effort in the development of the PVT-technology. This technology combines solar thermal, for space heating and/or domestic hot water, and PV in one module.

7.1. Comparison of PV, T and PVT

For different combinations of PV, T and/or PVT in combination with different thermal storage sizes the optimal gains in terms of primary energy have been simulated with MATLAB. The calculations are based on a 40m^2 roof area, south orientated, with a 30 degrees angle. The heat demand is based on a renovation dwelling BF concept with 9.9 GJ (2742 kWh) of space heating demand and 9 GJ (2493 kWh) of domestic hot water (DHW) demand. For the thermal systems vacuum tube collectors are used since they have higher gains in colder climates. The PVT collector is based on a flat plate collector. This means it is difficult to compare the thermal output of T and PVT systems. The m^2 collector area are absorber areas. Depending on the system size, a large (8 m^3) or small (0.2 m^3) storage is chosen. The large storage is modelled as a flat, rubber bag that can easily be placed in the crawl space beneath the ground floor.

The types of (combinations of) solar systems for a roof area of 40 m^2 that have been simulated are:

1. 100% PV (40m^2)
2. 100% PVT (40m^2)
3. 100% T (40m^2)
4. 100% T (with heat dump on district heating if temp > 90 ºC)
5. PVT(16 m^2), PV(24m^2),large storage(8 m^3)
6. T(6 m^2), PV (34 m^2), large storage (8 m^3)
7. T(21 m^2), PV(19 m^2), large storage (8 m^3)
8. T(4m^2), PV(36 m^2), small storage(0.2 m^3)
9. T(10m^2),PV(30 m^2), small storage (0.2 m^3)

7.2. Results

The results of the calculations are given in figure 10 Please note that the results of this comparison are only valid for this specific case and can not be seen as representative for all building types. Since each type of building has different heat demands and other available installation surfaces new calculations should be made. Please also note that all energy gains are given in kWh primary energy. For the conversion of PV electricity to primary energy a factor 2.5 is used.

Besides the comparison of the energy gains, also an indication of the costs is given for each combination of PV, PVT and or T systems. The cost estimates for collector systems per m^2 are €550.- for PV, €500.- for T (vacuum tubes) and €850.- for PVT. For the lifetime of all systems a period of 20 years is chosen. The cost assumptions are based on current prices (2008). Since the costs are rough estimations these figures should not be seen as exact costs. The figures however do give insight in the relative performance and are useful for mutual comparison of the systems.

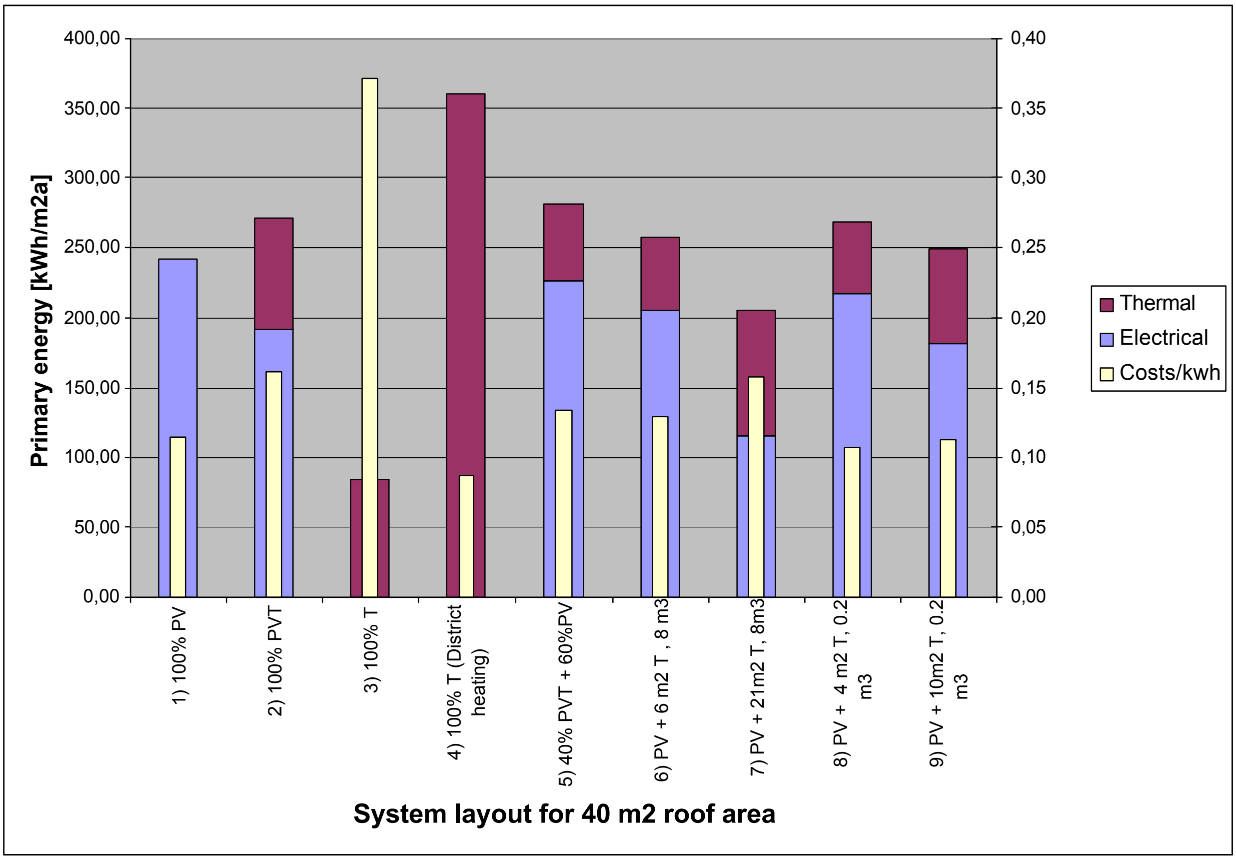

Figure 10. Comparison of different solar roof options

7.3. Conclusions

- The various combinations of PV, T and PVT give primary energy gains varying between 206 and 361 kWh/m^{2}a of roofing area, using a 40 m3 roof area. This accounts for 69 to 120kWh/m^2 of living area for a typical house (120 m^2).
- The highest and also the lowest gains are achieved with the same system layout: 40 m2 of thermal vacuum collectors. In option 3) the system is clearly oversized to provide the small heat demands while in option 4) the availability of a district heating system is assumed, so all excessive generated heat (majority in summer) with temperatures of 90 °C can be transferred to other locations. Although for space heating the system is not suited very well (low gains in winter) the DHW provision in summer can be interesting option.
- A roof combination of 40% PVT and 60% PV in this case gives the total highest gains. It has just a little more gains than a complete PVT roof due to the relatively decreasing thermal gains and the lower electricity gains of PVT compared to PV.
- A m^2 of PV gives 241 kWh primary energy per year and a m^2 of thermal vacuum tube gives 166-500 kWh/year, depending on the size of the system. Because of the relatively decreasing gains at larger system size of the thermal system a combination of PV and T has higher gains than PV or T separately.
- A m^2 PVT gives circa 20% less heat than a m^2 T vacuum and also gives circa 20% less electricity than a PV system. The total of thermal and electrical gains per m^2 however can be higher 271 kWh.
- The split-combination of a PV roof with a small thermal; system (4m^2 collector and 0.2 m^3 storage) scores just a little less than the PVT and PVT/PV combinations but in terms of costs of energy per m^2 it has the best score.
- A vacuum tube collector system of 10 m^2 can provide 85% of the DHW demand but only 20% for space heating.
- A roof covering PVT system gives a coverage of 50% on the combined heat demand for space heating and DHW
- Due to the relatively large surface area/content ratio of the flat storage tank, the systems with 8 m^3 storage are relatively inefficient, despite U=0.2W/m^{2}K. In fact the smaller system with only 200 liter storage performed better than the 8 m^3 storage
- Prices for the full roof systems range from €22,000.- for 40m^2 PV to €35,000- for 40m^2 PVT

7.4. Thermal comfort

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

8. OFFICE BUILDING FUTURE CONCEPTS

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.

Step one: minimize demand

In order to reduce energy demand for space heating, Passive house renovation standards are applied. Increasing insulation levels of walls, floor and roof (R_c>6.5) and replacing windows result in 90% reduction of heat demand. Heat recovery from ventilation air is achieved, using either a central balanced system or retrofitted facade-integrated systems.

Step two: use renewable

After minimizing demand, the resulting energy consumption of the office building shows a relative small heat demand compared to electricity need. Only 8% of total energy consumption is needed for space heating and Domestic Hot Water (DHW), opposed to 83% electricity demand. The other 9% is a cooling need. Renewable energy sources should be utilized in order to match this energy signature.

Vacuum tube collectors can contribute to fill in a large share of the heat demand for space heating and DHW. Excess heat can be transferred to a low temperature district heating system if available. In summer, the vacuum tube collectors can be utilized as thermal energy input for sorption cooling, contributing to the cooling need of the office building. For solar generated electricity, PV modules on roof and building skin can be applied. In this way, more than 60% of electricity consumption will be generated from sustainable resources.

Step three: efficient end use

Several measures contribute to efficient end use of electricity consumption:

- Occupant and daylight dependant lighting systems with HF lighting according to the standard for new office buildings
- Energy efficient ICT and building related office equipment

Implementing the above mentioned measures result in a 81% reduction of primary energy consumption, as illustrated in Figure 11.

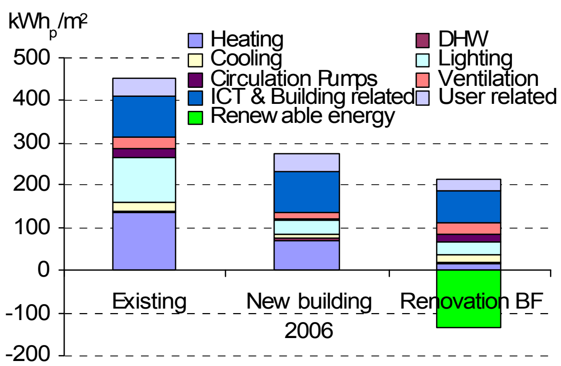

Figure 11. Impact of renovation measures on existing office building.

Figure 12. Impression of a retrofitted office building

9. 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 Building Future 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 Passive house measures), common practice and developing necessary technologies for essential concepts such as energy producing new to build residential buildings 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. Combinations of PV, T and/or PVT e.g. can provide the needed energy to compensate the heavily reduced energy demands of BF dwellings. Based on TRNSYS simulations and MATLAB calculations the requested energy performance of BF building concepts to reach energy neutrality in 2050 is seen as technically feasible. Whether or not the investments in energy saving and renewable energy are also economically feasible is largely depending on future development of energy prices.

REFERENCES

[1] Opstelten, I.J. e.a., WSED2007 – Energy Future 2030. Wels, Austria, 2 March 2007

[2] MNP, CPB, RPB; Welvaart en Leefomgeving (in Dutch), available as 500081001 at www.welvaartenleefomgeving.nl.

[3] Dril, A.W.N. van e.a., Reference projections energy and emissions 2005-2020, ECN 2005, available as ECN C-05-089 at www.ecn.nl.

[4] Zondag, H.A e.a., PVT roadmap: a European guide for the development and market introduction of PVT technology; November, 2005, available as ECN RX--05-170 at www.ecn.nl.

[5] Boer, B.J. de e.a., Optimale PZE woning (in dutch), ECN 2003 C-03-002. available as ECN- at www.ecn.nl.

[6] Boom, 'Energiebewust ontwerpen van nieuwbouwwoningen' (in dutch), ISBN 90-5748-017-4, 2000.