Innovative Concepts for Energy Neutral Districts in 2050

B. Jablonska

G.J. Ruijg

I.J. Opstelten

T. Epema[1]

E. Willems[2]

[1]**TNO**

[2]**Cauberg-Huygen**

Presented at the AES2010 Conference, 19-21 October 2010, Barcelona, Spain

ECN-M—11-037 March 2011

Transition to Sustainable Energy Neutral Districts before 2050: Innovative Concepts and Pilots for the Built Environment.

Jablonska, B.[*]*; ECN, The Netherlands*

Ruijg, G.J.; Opstelten, I.J.; ECN, The Netherlands; Willems, E.; Cauberg-Huygen Consulting Engineers (CHRI), The Netherlands; Epema, T.; TNO, The Netherlands

ABSTRACT

The Dutch project 'Transition in Energy and Process for a Sustainable District Development' focuses on the transition to sustainable, energy neutral districts in 2050, particularly in energy concepts and decision processes.
The main objective of the technical research is to develop four to six innovative energy concepts for 2050 for the four Dutch cities of Almere, Apeldoorn, Nijmegen and Tilburg, as well as the roadmap for realising this target.
Firstly, 14 variations of six general energy concepts have been developed and calculations conducted on the energy neutrality in 2020, 2035 and 2050 by means of an Excel model designed for this purpose.
Three concepts are based on the idea of an energy hub (smart district heating, cooling and electricity networks, in which generation, storage, conversion and exchange of energy are all incorporated): the geo hub (using waste heat and/or geothermal energy), the bio hub (using waste heat and/or biomass) and the solar hub (using only solar energy). The fourth concept is the so-called all-electric concept, based predominantly on heat pumps, PV and conversion of high temperature heat from vacuum collectors to electricity. The fifth concept uses only conventional technologies that have been applied since the second half of the previous century, and the sixth one uses only hydrogen.
Calculations show that by implementing the hub concepts, the energy neutrality in 2050 ranges from 130 % (solar hubs) to 164% (geo hubs), excluding personal transport within the district.
With the all-electric concept, an energy neutrality of 157% can be reached. Hydrogen only and Conventional concepts perform worse, but nevertheless reach an energy neutrality of around 115% in 2050.
The energy neutrality shows the extent to which a district, in which the given concept is implemented, can supply itself with sustainable energy generated within the boundaries of that district.
Based on the six general concepts, the most optimal energy concepts tailored for the involved four cities have been drawn up and elaborated as pilots, in close cooperation with the representatives of the involved municipalities.
The research up to now has shown that it is possible to realise energy neutrality in 2050 by implementing innovative technical concepts on district level. In this approach, different districts have different sustainable energy potentials that have their peak supply at different times. The smart approach therefore is not the autarkic district, but an exchange of surplus sustainable energy with neighbouring districts and import of the same amount of energy in case of a shortage.

Keywords: energy neutrality, district, energy concept, energy hub, all-electric

1. INTRODUCTION

[*] Tel.: +31-224-568130; Jablonska@ecn.nl

To many of us the year of 2050 seems too far away to be occupied with it. Nothing could be further from the truth! Certainly not if we wish to break our addiction to fossil fuels and aim at living in energy neutral neighbourhoods in 2050. To reach this future vision, we need to take certain steps today, develop innovative and integral energy concepts for renovation and new housing and apply them to entire districts.

One third of the current Dutch (and European) energy demand comes from the built environment. A characteristic of the built environment is that it changes very slowly. Each year, 1% of new buildings is added to the existing building stock. The buildings constructed now will still be here 50 years later.

The target of the Dutch government, in accordance with the European targets, is to reach 20% renewable energy supply in 2020 [PEGO, 2009]. The document [New Energy for the Netherlands, 2009] contains a plea of the leading political parties in favour of a completely renewable energy supply in 2050.

The innovative energy concepts can contribute to these targets. Moreover, the progressive municipalities hold a tool in their hands that can be used to realise their energy visions in the long term.

2. ENERGY NEUTRAL DISTRICT

An energy neutral district, as defined in this project, does not have to follow the municipality boundaries and consists of a mix of residential and commercial buildings. It is assumed that the energy for industry and transport other than personal transport is generated outside the district boundaries. Furthermore, the agricultural areas and energy sources from outside the district, such as wind turbines (for example offshore) and biomass (forests, agricultural sources), are excluded.

One exception is waste heat from large-scale incineration and combustion plants, which process mainly waste from the district such as domestic and company refuge.

A district is energy neutral if, on a yearly base, no net energy import is necessary from outside the district. An energy neutral district is not an autarkic district that does not exchange any energy with its surrounding districts. Surplus of energy can be exported and, in case of energy shortage, the same amount of energy can be imported from the surrounding districts. It is better to import or export electricity than to store it.

3. TRIAS ENERGETICA

The design of energy neutral districts follows the three steps of the Trias Energetica, while the need of energy storage, exchange and conversion is emphasized. The Trias Energetica for energy neutral districts can be detailed in five steps:

1. Limit energy consumption
2. Use renewable energy optimally
3. Exchange energy in energy hubs and in smart grids
4. Buffer energy on day, week and season scales in order to match the demand and supply of renewable energy

5. Use imported energy and fuel efficiently in case of shortage in renewable energy generation, and in case of emergency.

In Figure 1 below, the Trias Energetica for energy neutral districts is represented in five steps. All of these five steps are equally important and should be considered in any innovative energy concept.

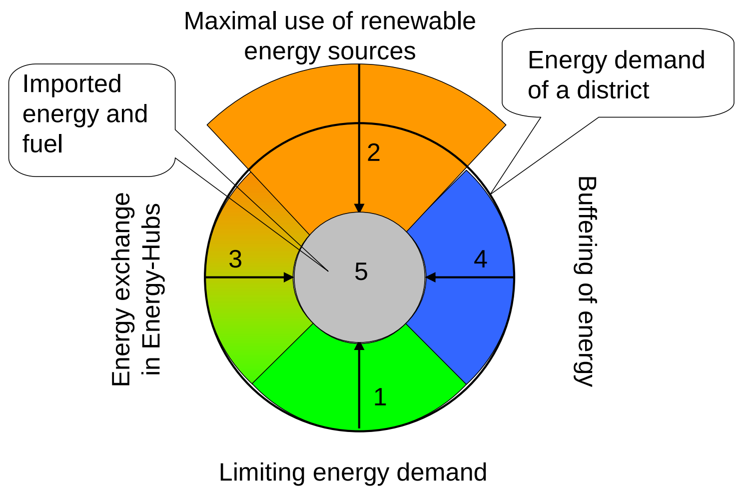


Figure 1: Trias Energetica for development of energy neutral districts in five steps [Willems, 2010]

4. FUTURE ENERGY HOUSEKEEPING

The starting point for establishing the energy demand of the innovative concepts in 2050 is based on the so-called Building Future Potential Study 2050 [Koene et al; 2008] and [Visser, et al; 2009]. According to this study, the main features of the energy system in 2050 are as summarized below (Figure 2):

- The energy demand of a district can be broken down in the energy demand of:
  - Buildings
  - Transport in the district and
  - The surroundings of the buildings in that district.
- Due to a far-reaching reduction of demand in 2050, the total average energy demand of a house will be approximately 33 GJ annually, broken down in:
  - Hot water (4.5 GJ or 185 m^3 gas annually)
  - Space heating (6.5 GJ or 300 m^3 gas annually)
  - Electricity (9 GJ or 2,450 kWh annually)
  - Electricity demand outside buildings (0.3 GJ annually)
  - Cooling demand (1.6 GJ or 300 kWh_e annually) and
  - Personal transport (11 GJ annually).

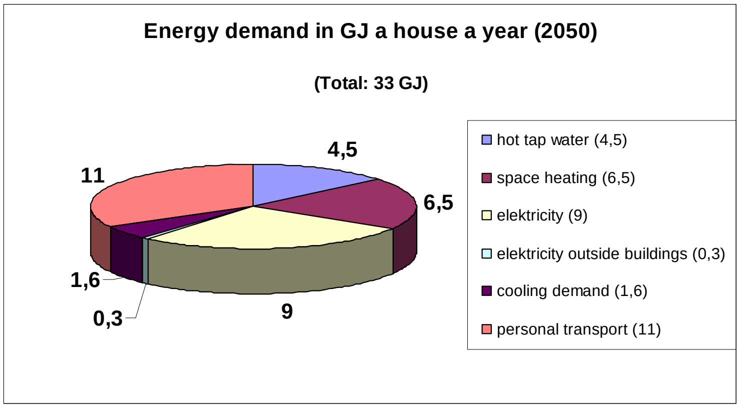


Figure 2: Annual energy demand of a house in GJ, assessed for 2050 [ECN, 2009]

5. TECHNOLOGIES OF THE FUTURE

Renewable technologies that can be deployed in innovative energy concepts can be classified as existing, future (within app. 10 years) and still to be developed technologies (after 2020).
Existing renewable technologies comprise of high and low temperature district heating networks, geothermal sources, heat and cold storage, flat plate and vacuum tube solar collectors, heat pumps, heat-driven cooling, PV (photovoltaic modules), urban wind energy and biomass. The future renewable technologies are, among others, organic rankine cycle (ORC), heat pump booster, electricity hub, heat and power matcher, compact season heat storage and hydrogen as an energy carrier. Still to be developed renewable technologies are, among others, bi-directional district heating networks, heat hub and energy hub.

6. ENERGY HUBS

An energy hub is a central point in a district where all energy distribution systems meet each other and energy flows can be converted. Vehicles can be refuelled with (bio)gas or liquid biofuel there, for example. (Bio)gas can be used for combined heat and power systems in order to generate heat and electricity. Electricity can be used to charge electric vehicles and to generate heat or cold with heat pumps. Energy hubs will probably be equipped with seasonal storage of heat and cold. Energy management, based on the PowerMatcher™ (Figure 3) and HeatMatcher (under development) technology will be used to coordinate the generation, supply and demand of all energy flows and conversions. The energy hub makes sure that the entire renewable energy generation potential of all connected systems will be exploited to its maximum.

Figure 3: Supply and demand matching with the PowerMatcher™ [ECN, 2009]

7. DEGREE OF ENERGY NEUTRALITY

The performance of innovative energy concepts has been calculated in an Excel model. The energy performance is expressed in terms of "degree of energy neutrality" (or energy self-sufficiency). The degree of energy neutrality is defined as the renewable energy generated in a district, divided by the energy demand of that district. If the degree of energy neutrality is higher than 100%, this means that the district can export energy surplus. Values under 100% mean that the district needs to import renewable (or fossil) energy in order to meet its energy demand.

8. ENERGY CONCEPTS FOR 2050

Six types of energy concepts on a district scale have been developed by means of well considered combinations of the above mentioned technologies:

1. Geo hubs
2. Bio hubs
3. Solar hubs
4. All-electric
5. Conventional concepts and
6. Hydrogen concepts

Within these six general concepts, 14 variations have been elaborated. The energy performance, which is expressed as the degree of energy neutrality, has been calculated for each concept variation for the years 2020, 2035 and for 2050.

The first step in all energy concepts consists of limiting the energy demand by means of building or renovating according to the passive house standard. Newly built buildings reach the passive house standard by an excellent building envelope (insulation and air tightness), low temperature space heating and heat recovery from ventilation air. The heat demand for newly built passive dwellings is 15 kWh/m^2 of floor area annually. Renovated houses have a higher heat demand: 28 kWh/m^2 of floor area annually. Both types of houses also have heat recovery from waste water.

The average roof area suitable for solar energy generation systems such as solar collectors, PV and PVT (combined solar collector and PV) will increase in time up to 28.1 m^2 per dwelling. The increase of the available roof area is mainly due to the increasing southern orientation of the buildings.
The energy concepts have been summarized in Table 1 below.

	ENERGY CONCEPTS	Individual or collective	Cooling	Degree of energy neutrality [%] 2020		2035		2050	
				Transport excl	incl	excl	incl	excl	incl
1	**Waste Heat and/or Geothermy (Geo-Hubs)**								
	High temperature waste heat utilization or geothermy	District heating	Compression cooling by PV or sorption cooling by solar	96	61	120	73	**164**	**96**
2	**Waste Heat and/or Biomass (Bio-Hubs)**								
	Moderate temperature waste heat utilization	District heating	Compression cooling by PV or sorption cooling by solar	93	60	119	72	**163**	**95**
3	**All-Solar concepts (Solar-Hubs)**								
	High temperature storage of solar heat	District heating	Compression cooling by PV or sorption cooling by solar	53	34	73	45	**130**	**76**
	Low temperature storage with ORC or heat pumps			47	30	72	43	**131**	**76**
4	**All-Electric concepts**								
	Individual electric heat pumps, PV and solar collectors	Individual	Free cooling by ground heat exchanger	71	45	102	61	**150**	**87**
	Individual electric heat pumps and PV			73	47	106	64	**157**	**92**
5	**Conventional concepts with PV**								
	Individual gas boilers with PV	Individual	Compression cooling by PV	36	23	64	38	**112**	**65**
	Individual gas boilers, solar collectors and PV		Compr. or sorpt. cooling by solar	38	24	65	40	**114**	**67**
6	**Hydrogen concepts**	Individual	Free cooling by ground heat exch.	15	7	57	30	**115**	**54**

Table 1: Degree of energy neutrality of the concepts in 2020, 2035 and 2050 [ECN]

In 2050, all concepts can reach full energy neutrality, unless personal transport in the district is included.

9. PILOTS IN FOUR DUTCH CITIES

The above mentioned general energy concepts serve as a blueprint for the selection of specific energy concepts for the participating municipalities. The choice depends on several aspects such as the district features, availability and type of energy sources, characteristics of the existing buildings and the infrastructure, size of the district and the energy visions of the municipalities. After all, the economy of an energy concept will often be the decisive aspect in the selection of a concept.

9.1 City of ALMERE - The Kruidenwijk

The Kruidenwijk residential area, located in the Northwest of the city of Almere, is characterized by low-rise buildings from the 1980s (Figure 4). The Noorderplassen lake can be found north of the residential area. The lake is approximately 20 meters deep and is used as a well for extracting sand. The houses have predominantly flat roofs and more than half of the houses is oriented to the south. Facades can be easily upgraded to the passive house standard.
There is a district heating network with high temperature heat in the Kruidenwijk. The network also extends to other districts in the city.

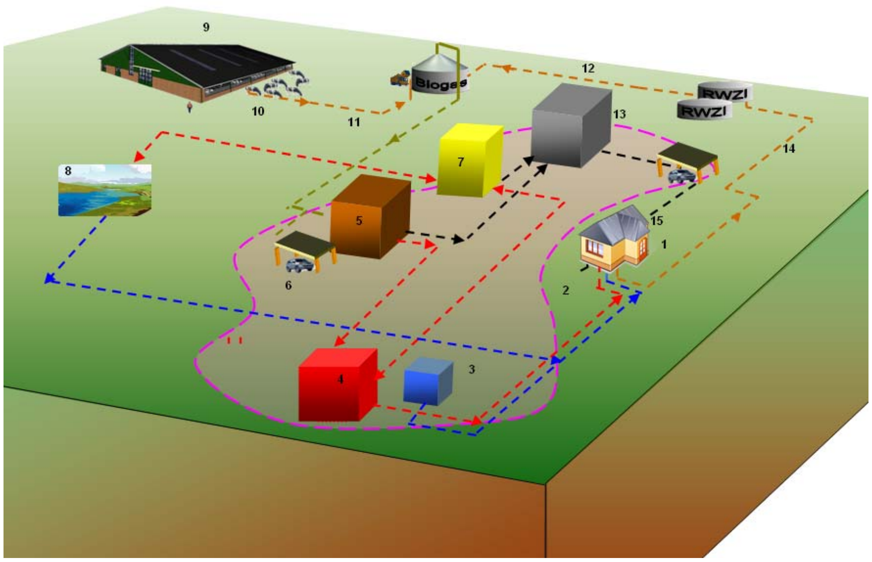
Because of the existing district heating network and the Noorderplassen, energy concept 1 (high temperature geothermal heat) with a possible contribution of biomass (concept 2) has been selected for the Kruidenwijk district. If geothermal energy is proven to be unfeasible, then concept 3 (low temperature storage in the Noorderplassen lake with ORC) and/or heat pumps is preferred.

Figure 4: An example of dwellings in the Kruidenwijk residential area [Ymere]

9.2 City of APELDOORN - The Kanaalzone Noordoost

The Roadmap 2020 [Apeldoorn is bursting with energy; 2009], amended in 2010, expresses the aspiration of Apeldoorn to become 100 % energy neutral in 2035. The Apeldoorn municipality aims at an all-electric concept with small-scale district heating networks if needed.
The Kanaalzone Noordoost will be restructured until 2025 [Masterplan Kanaalzone Noordoost, 2009]. The district is characterized by a mix of existing buildings, newly built housing and small-scale industry. A part of the Kanaalzone Noordoost will serve as a recreational area. A channel flows through the whole district. The present industrial buildings will be replaced by offices and dwellings. The Apeldoorn municipality strives for a combination of living and working while the small-scale character and cultural, historical and natural values will be preserved.
Biomass and domestic refuge will not be used directly as an energy source in the district, but will be transported to the biogas generation units outside the district. The biogas will be upgraded to natural gas quality and transported back to the city where it will be converted into heat and electricity in combined heat and power installations on biogas. The ground of Apeldoorn is probably suitable for generation of renewable heating and cooling energy. The remaining cooling demand is expected to be low (contrary to offices, passive houses have no significant cooling demand) and can be generated by heat and cold storage in the groundwater. Heat can be generated by electric heat pumps (ORC in winter mode).
To be able to use the channel in Apeldoorn for generation of heating or cooling it is necessary that the water flows sufficiently. At present, the channel water is nearly stagnant but it can be made to flow. This can be achieved by pumping the water up and letting it flow back into the channel at certain locations outside the district that have the required level differences.

In view of the aspiration of the Apeldoorn municipality and the Kanaalzone Noordoost characteristics, concept 4 (all-electric) combined with concept 3 (low temperature storage with ORC or heat pumps) seem to be the most suitable option (Figure 5).



1 – Dwelling
2 – Solar heat
3 – ABS1 chiller
4 – Heat hub
5 – Combined heat and power
6 – Fuel tank
7 – ORC
8 – Channel
9 – Stables
10 – Fertilizer
11 – Biogas
12 – Sludge
13 – Electricity Hub
14 – Sewage
15 – PV

Figure 5: Energy flows in the Kanaalzone Noordoost area

9.3 City of NIJMEGEN - Waalfront, Waalsprong and the city centre

The Waalsprong is a residential area with 8,500 low-rise houses built early in the 21st century, north of the river Waal and opposite the city centre. The Waalfront is a former industrial area west of the city centre and at the south bank of the Waal, where approximately 2,650 houses will be built. Many houses in the city centre are up for renovation.

These three locations together can become energy neutral in 2050. The new housing in the Waalsprong and Waalfront areas will have a net energy surplus, providing the city centre with energy. Because of the existing and especially historical buildings, and relatively small roof area for renewable energy generation it seems improbable that the city centre itself could become energy neutral.

The Nijmegen municipality has the aspiration to achieve energy neutrality in the Waalsprong by implementing a hybrid district heating network [Roos et al; 2009].

In the near future, a bypass of the river Waal will be realised, thus creating two islands. The river Waal can be used for cooling and for generating energy from the flow. The cold will be used mainly in offices.

An aquifer supplies cold that can be directly used for cooling of buildings. Heat can be generated from the aquifer by electric heat pumps.

A geothermal source built as a doublet offers a possibility for extracting high temperature heat. This doublet can serve as a temporary storage for excess high temperature heat, including solar heat generated by vacuum tube solar collectors.

The waste treatment plant in the district also supplies heat (40-50ºC) that is not at the expense of the electrical efficiency. The coal- and partly biomass-fuelled Electrabel G13 power plant supplies waste heat to companies in its vicinity. The G13 will be closed down in 2035.

Because waste heat is available in Nijmegen and there are enough possibilities for generating geothermal and solar energy, and due to the river Waal , concepts 1 or 2 have been selected (geo hub or bio hub with moderate temperature waste heat utilisation). A combination with concept 3 (solar hub with high temperature central storage of solar heat) is possible.

9.4 City of TILBURG - Tilburg North

Tilburg North will be re-developed until 2020. The extensive maintenance of approximately 1,100 houses (year of construction is 1965-1970) has been planned for the near future. At the same time, a new housing development of 700-800 houses will be realised at the north side of the city.
The largest part of the city has a district heating network. The high temperature network is fed by the waste heat from the coal-fuelled Amer power plant.
The aspiration of the Tilburg municipality is to become energy neutral in 2045. One of the main targets is making the existing district heating network as energy-efficient and environmentally friendly as possible. The Tilburg municipality also intends to realise large scale heat and cold storage.
If the Amer power plant closes down, the solar collectors and combined heat and power plants on biogas, possibly combined with geothermal heat, can feed the district heating network. Heat storage will take place by means of compact thermo-chemical heat storage applied in the houses and/or by geothermal doublets. In principle, electricity storage will not take place in the energy hub, but in the batteries of electric vehicles. Vehicles will be connected to the electricity grid of houses and other buildings. This is feasible due to the so-called Vehicle-to-Grid system (V2G, under development). Electricity that cannot be stored this way can be exchanged with the rest of Europe.
The city of Tilburg has the ambition to upgrade the district heating network in an energy-efficient and environmentally friendly system and since there are enough renewable energy sources that enable the continuation of this network, the energy hub concept is suitable. In the district, a transition from concepts 1 or 2 (geo or bio hub with high temperature waste heat utilisation, using biomass) to concept 3 (solar hub with high temperature storage of solar heat) will take place.

10. CONCLUSIONS

Based on the conducted research the following conclusions can be drawn:

- Energy neutrality of the built environment can only be reached by an extensive reduction in energy demand. Sun oriented new buildings and new and renovation building development according to the passive house standard, and development of high-performance heat recovery from waste water are essential.
- In 2050, energy neutrality is feasible with all the elaborated concepts. The geo and bio hubs and the all-electric concepts lead to the highest degree of energy neutrality, followed by solar hubs. Conventional and hydrogen concepts realise the energy neutrality only barely. The fact that all elaborated concepts lead to energy neutrality in 2050 or earlier means that the transition based on the current energy infrastructure is possible. This way, the investments already made will not be lost.
- Based on the assumptions made here, energy neutrality of the built environment including personal transport is not feasible within a district. The energy consumption for personal transport will still be too high in 2050.

11. FOLLOW-UP STEPS

The research will be continued on various aspects of the above-mentioned energy concepts.
The Excel calculation model provides the degree of energy neutrality for 2020, 2035 and 2050. In 2050 and in some cases also in 2035, values higher than 100% occur. It is interesting to see which energy concepts or combination of concepts is for the involved municipalities the best to reach a certain degree of energy neutrality in certain year, for example 20% energy neutrality in 2020, 50% in 2035 and 100% in 2045. This approach shows the difference between a feasible and desired degree of energy neutrality and thereby a freedom of choice, for example to carry out financial-economic optimisation of the concepts to be selected.
The energy hub concepts seem very promising. It would be interesting to elaborate various types of energy hubs.
An energy hub will be dynamically simulated in order to prove the added value of the exchange, conversion and storage of the energy flows within a district.
Next to the energy and CO_2 reduction, a further research can be done on exergy, clever utilisation of temperature levels of energy flows within an energy hub.

ACKNOWLEDGEMENTS
The authors would like to thank the Ministry of Economic Affairs of the Netherlands for their financial support of this research within the Energy Research Subsidy regulation (EOS) – long term –, and Mr Sander Koomen (Ymere housing association in Almere); Ms Marleen Bijker and Mr Theo van Es (municipality of Apeldoorn); Mr Fons Claessen and Mr Harm Eetgerink (municipality of Nijmegen) and Mr Pieter Biemans (municipality of Tilburg) for sharing information and their enthusiastic cooperation.

References:

Apeldoorn barst van de energie (2009): (Apeldoorn is bursting with Energy)

Koene, F. G. H.; Knoll B. (2008): Renovation concepts for saving 75% on total domestic energy consumption, Eurosun Conference, Lisbon, Portugal.

Masterplan Kanaalzone Noordoost, 2009

Nederland krijgt nieuwe energie (New energy for the Netherlands) (2009): http://www.nederlandkrijgtnieuweenergie.nl/main.asp

PEGO (2009); Stevige ambities, klare taal (Strong ambitions, clear language). Platform Energietransitie gebouwde omgeving (PEGO); Utrecht, the Netherlands.

Roos, J.; Braber, K.; Willems, E.; Pfeiffer, E.; Kaandorp, A. (2009): Hybride LT-warmtenet (Hybrid LT heating grid); Waalsprong Nijmegen; report number: 80313, BuildDesk Benelux B.V.

Visser, H.; Koene, F.G.H.; Paauw, J.; Opstelten, I.J.; Ruijg, G.J.; Smidt, R.P. de (2009): Sustainable energy concepts for residential buildings, Packages of current and future techniques for an energy neutral built environment in 2050, ECN-E--09-021. ("Building Future Potential study 2050"), ECN, Petten, the Netherlands