Energy Neutral Districts?

Key to Transition towards Energy Neutral Built Environment!

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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 research results in six innovative energy concepts for 2050.
Firstly, fourteen variations of six general energy concepts have been developed and calculations conducted on the energy neutrality 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). Calculations show the energy neutrality ranges from 130 % to 164% excluding transport of persons within the district.
In this approach, different districts have different sustainable energy potentials that have their peak supply at different times. The smart approach therefore is not an 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

One third of the current Dutch (and European) energy demand is caused by the built environment. 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.
A characteristic of the built environment is that it changes very slowly. Each year, 1% of the floor area of existing building stock is added to the total building stock. With a minimal lifespan of buildings of one hundred years we need to take action today to reach this vision before 2050 or even this century if we wish to break our addiction to fossil fuels. We need to develop innovative and integral energy concepts for renovation and new housing and apply them to entire districts.

Energy neutral houses are already demonstrated mainly as villa's or special designs [1]. In ordinary cities, existing buildings and newly built districts it is impossible to reach energy neutral houses on a large scale with these common technologies. For offices it is even more difficult to gain energy neutrality [2]. Only within district energy neutrality can be achieved. It can be concluded that there is a need for using sustainable sources on an district scale.

2. Future Energy Housekeeping

The starting point for establishing the energy demand of the energy neutral concepts is based on the Building Future Potential Study 2050 [2] and [4]. According to this study, the main features of a energy neutral district are as summarized below (Fig. 1):

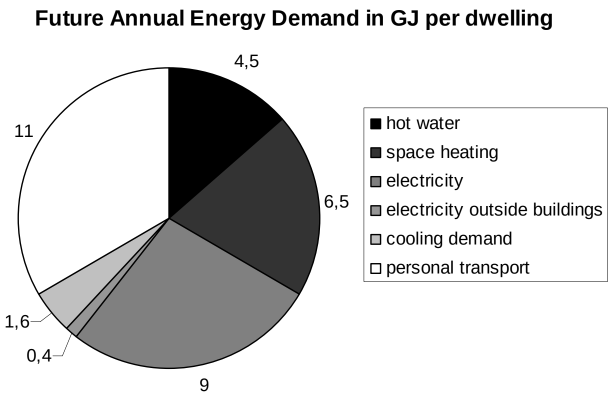

Fig. 1: Annual energy demand of a house in GJ, assessed for 2050 [ECN, 2009]

The energy demand of a district separated into the following components: (1) Buildings, (2) Transport for persons within the district and (3) the surroundings of the district. Due to a far-reaching reduction of demand in future, the total average energy demand of a dwelling will be approximately 33 GJ annually, separated into:

- Domestic Hot water (4.5 GJ or 185 m^3 natural gas)
- Space heating (6.5 GJ or 300 m^3 natural gas)
- Space Cooling (1.6 GJ or 300 kWh_e)
- Electricity for lighting and household appliances (9 GJ or 2,450 kWh)
- Electricity demand for street lighting etc (0.3 GJ)
- Transport of persons (11 GJ).

Energy losses due to distribution of heat:

- high temperature (90-70 C): 5 GJ per meter with high performance insulation
- low temperature (50-30 C): 2.5 GJ per meter

The energy demand for transportation of persons within a district is established as 34 GJ primary energy use of 11 GJ electricity [5].

3. Understanding energy neutral districts

An (energy neutral) district, as defined in this research, follows the boundaries of the built area and consists of a mix of residential and commercial buildings. This implies that energy sources from outside the district, such as wind turbines (for example offshore) and biomass (forests, agricultural sources) are not taken into account. It is assumed that the energy for industry and transport other than personal transport is generated outside the district boundaries.

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

We consider a district as 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. This definition is according to PEGO [6].

3.1. Technologies used in energy neutral concepts

Technologies needed to be deployed in energy neutral concepts can be classified as existing, future (on the market within app. 10 years) and still to be developed technologies (market ready after 2020). Existing renewable technologies comprise of high and low temperature district heating networks, geothermal sources, heat and cold buffering in storage tanks, Aquifer Thermal Energy Storage (ATES), flat plate and vacuum tube solar collectors, heat pumps, heat-driven cooling, PV (photovoltaic modules), urban wind energy and biomass CHP. The future technologies are, among others, organic rankine cycle (ORC), heat pump booster, electricity hub, heat and power matcher, thermal chemical heat storage (TCS) and hydrogen as carrier and storage of sustainable energy. Still to be developed technologies are, among others, bi-directional district heating networks, heat/cold hub and energy hub.

In addition to this it is assumed that the primary energy use per produced kWh electricity delivered to the power grid will decrease. Nowadays the energy-efficiency has an average of about 39%. This efficiency will increase in 2050 towards 50%.

3.2. Energy hubs

An energy hub is defined as a central point in a district where all energy distribution systems come together and energy can be converted to other energy carriers. In addition vehicles can be refuelled with (bio)gas or liquid bio-fuel 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 2a) and HeatMatcher (Figure 2b, 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.

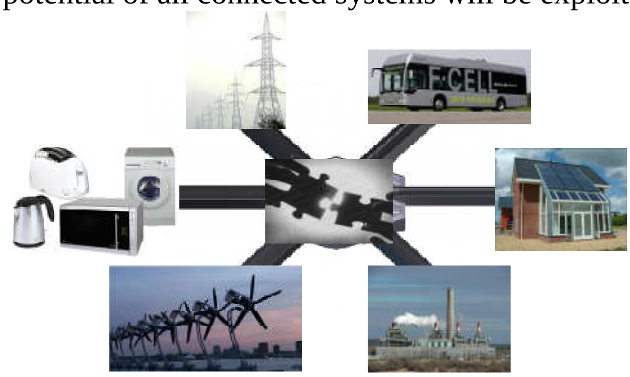

Fig. 2a: Supply and demand matching with the PowerMatcher™ [ECN, 2009]

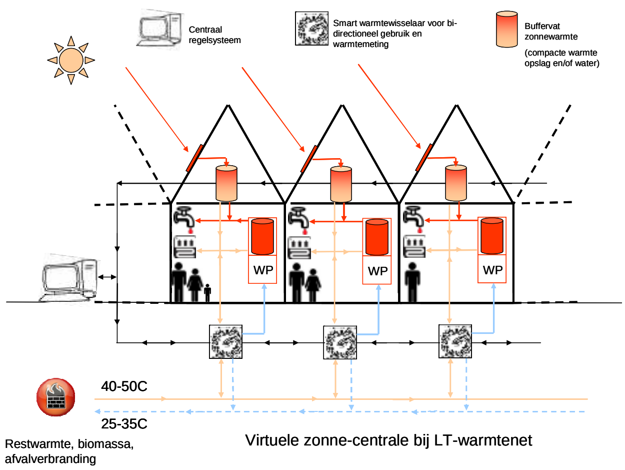

Fig. 2b. Part of a smart heat grid with solar collectors (under development; Willems, 2010)

4. Quantification energy neutrality and sustainable energy surplus

The results are 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 in terms of heat, cold or electricity. Values under 100% mean that the district needs to import renewable (or fossil) energy in order to meet its annually energy demand. Shortage and surplus are expressed in primary energy. It can be shown that the energy neutrality is not strictly depending on the energy demand but of the combination of demand en supply of sustainable energy.

5. Six concepts for energy neutral districts

Six types of energy concepts on a district scale have been developed by means of well considered combinations of the above mentioned technologies. The names of the concepts are derived from its main sustainable energy source: Geo hubs, Bio hubs, Solar hubs, All-electric Natural gas concepts and Hydrogen concepts.
Within these six general concepts, fourteen variations have been elaborated. The energy performance, as expressed as the degree of energy neutrality, has been calculated for each concept variation for the years 2020, 2035 and for 2050. These steps give as an example insight in what steps de maximum energy performance can be increased in time.

5.1. Description and performance

The first step in all energy concepts consists of limiting the energy demand by means of refurbishing or renovating according to the passive house standard for existing buildings (Renovated houses have a higher heat demand: 28 kWh/m^2 of floor area annually.). 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. Both types of dwellings 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 thermal solar collector and PV) is assumed to increase in time up to 28.1 m^2 per dwelling. This increase mainly is caused by making use of southern orientation of the roofs or other construction possibilities that provides the use of solar energy.
On the supply side the main sustainable district sources are thermal energy: geo, bio and solar; electrical energy through PV-panels and urban wind turbines.
In view of the aspiration of an imaginary municipality, concept 4 (all-electric) combined with concept 3 (low temperature storage with ORC or heat pumps) is given as an example of the applications of the developed concepts (Figure 3).

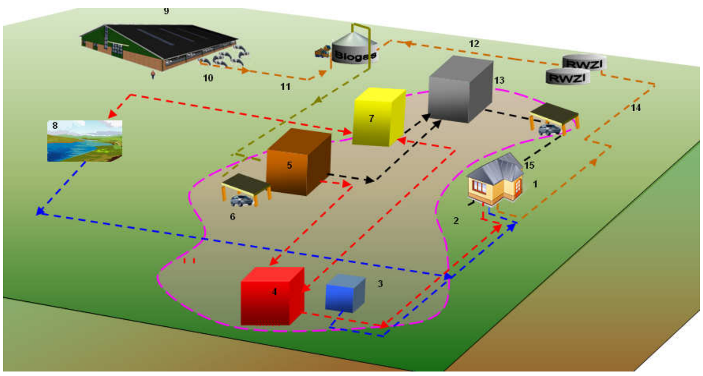

Fig. 3: Energy flows in an imaginary district

1 – Dwellings
2 – Solar heat
3 – ABS chiller
4 – Heat hub
5 – CHP
6 – Fuel tank
7 – ORC
8 – Canal/surface water
9 – Stables
10 – Fertilizer
11 – Biogas
12 – Sludge
13 – Electricity Hub
14 – Sewage
15 – PV-panels

The energy performance of the energy concepts has been calculated in an Excel model.

The performance of the main energy concepts and their related variations are presented in Table 1 below.

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

	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**

In 2050, all concepts can provides in a energy surplus, unless personal transport in the district is included.

5.2. Interaction between district energy concepts and scale

The actual size of a district is determined by the energy losses of the heat transport grid. Too long transportation pipes (heat) give high losses (about the same quantity) compared to the energy demand. Several energy concepts together perform energy neutral districts on a larger scale than apart due to energy exchange by energy hubs where a meso scale develops. On a macro scale we can imagine geothermal energy and large scale wind turbines. The areas between the built environment (e.g. agricultural land, oceans) can provide in wind, bio mass and hydro power for other purposes than the built environment (industry transport etc). Examples are given in table 2.

Table 2. Techniques per scale of energy concepts

Micro level (1-40 houses)	Meso level (40-4.000 houses)	Macro level (> 4.000 houses)
Solar energy	Bio mass	Bio mass
ATES / ground source heat pump	ATES	Mine water energy
PV-panels	Geothermal energy	Geothermal energy
Urban wind turbines		Large scale wind turbines

In figure 4 visualisation of the interaction between energy neutral concepts is given. Smallest circle is representing the scale of an energy concept on micro level.
In this vision energy concepts based on natural gas only have a function if only a part of the built environment is energy neutral. Through energy hubs the surplus of sustainable energy can be used in other districts. In case of only energy neutral districts except one there is a surplus on renewables and still using natural gas, an unwanted situation.

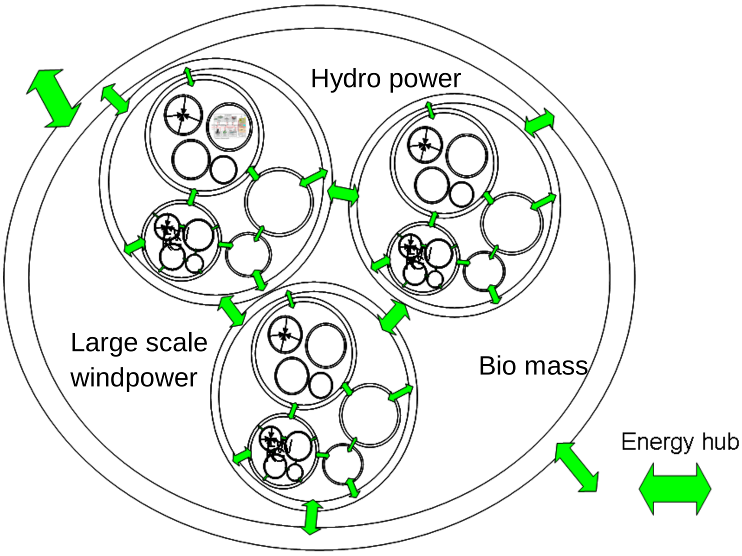

Fig. 4.Visuliasation of the scale and interaction between energy neutral district concepts (Willems 2010 [7]).

5.3. Robustness and sensitivity

Sensitivity analysis are grouped in three classes: screening methods like OAT-method (One-Parameter-At-a-Time), local sensitivity methods and global sensitivity methods [8]. In the sensitivity analysis of the Excel tool, a screening method is used, because is a relatively simple method that can identify and qualitatively rank the parameters that has the most influence of the tool's outcome. To evaluate the robustness of the calculations on the energy concepts energy performance a short sensitivity analysis is performed. These values are specified in Table 3 as averages per dwelling.

Table 3. Input parameters used in the sensitivity analysis, including the stratified samples per parameter

Parameter	Unit	Discrete values				
ATES efficiency	[-]	*20%*	*40%*	*60%*	*80%*	*100%*
Space Heating	$[GJ_t]$	4.5	6.5	8.5	10.5	12.5
Domestic electricity usage	$[GJ_e]$	*70%* 8.8	*85%* 10.7	*100%* 12.6	*115%* 14.5	*130%* 16.4
Percentage renewables national generation	$[GJ_{pe}/GJ_e]$	*20%* 1.6	*30%* 1.4	*40%* 1.2	*50%* 1.0	*60%* 0.8

The sensitivity index is defined as a percentage of the output difference of the extreme values according to:

$$SI = \frac{\text{Emax - Emin}}{\text{Emax}} x 100\% \quad (1)$$

where the maximum and minimum degree of energy neutrality are represented by respectively E_{max} and E_{min}. The results of the screening analysis are illustrated in Table 4.

Table 4. Sensitivity Index of the varied parameters per concept first impression analyses

Parameter	Concept													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ATES efficiency					56%	57%	30%	30%						
Space heating	16%	16%	16%	16%	25%	16%	25%	24%	19%	20%	39%	37%	37%	19%
Domestic electricity usage	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	40%
Percentage renewables national generation	13%	13%	13%	13%	4%	3%	3%	4%	9%	11%	29%	21%	21%	1%

Energy concepts with heat hubs have a surplus in sustainable heat. They are less sensitive to energy demand of heat. Energy concept that have a surplus on electricity are very sensitive to de efficiency of the power grid as well as very sensitive to de heat demand. The figures in table 4 show that de heat-hub concepts are more robust than the all-electric and natural gas concepts.

6. Conclusions

The aim of a built environment without any need of fossil fuels is still ambitious but becoming a realistic goal. Building techniques and energy storage will become market ready in 10-20 years an will provide the missing links in the energy concepts.

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 standards and development of high-performance heat recovery from warm waste water are essential.
- In 2050, energy neutrality is feasible with several energy 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 can remain profitable.
- Based on the assumptions made here, energy neutrality of the built environment including personal transport is not feasible within a district. Because the production of renewables in maximized only energy neutrality with personal transport can be reached by reducing transport or increasing efficiency of transport vehicles.
- Energy concepts with sustainable heat form local sources (ground, biomass, solar) are more robust due to changes in energy demand and efficiency of the power grid. It can be derives that diversification of sustainable energy sources is preferred above all-electric.

7. Follow-up steps

The research will be continued on various aspects of the above-mentioned energy concepts. The energy hub concepts seem very promising. It would be interesting to elaborate various types of energy hubs to a level of preliminary design for certain cases in communities and districts as presented by ECN [9].

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 clever utilisation of temperature levels of energy flows within an energy hub.
For future investigation it appears that the availability of sustainable sources becomes more important than the specific efficiency rates in energy conversion. In case of complete energy neutral districts only availability of the appropriate cost effective energy carrier for a specific energy demand is of importance, not the way it is generated or converted.

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