Concept for a DC low voltage house

Maaike M. Friedeman[1]
Elisa C. Boelman Dr. Eng., MBA[1]
Arjan van Timmeren, Ir. [1]
Joop Schoonman, Prof. Dr. [2]

[1]TU Delft, Faculty of Architecture, dept. of building technology, PO Box 5043, 2600 GA Delft, The Netherlands, E-mail: mfriedeman@hotmail.com.
[2] Delft Institute for Sustainable Energy, Julianalaan 136, 2628 BL Delft, The Netherlands.

1. INTRODUCTION

As a result of increasing environmental concern, the impact of electricity generation on the environment is being minimised and efforts are being made to generate electricity from renewable sources. Although widespread use of renewable energy sources in electricity distribution networks is still far away, high penetration levels may be reached in the near future at a local level in new suburban areas, where much attention is paid to renewable energy, One of the sources to be used is the sun. Due to the intermittent nature of solar energy supply, stand-alone PV systems require electricity storage. In locations where a public electricity grid is available, 'storage' by grid connection is usually considered to be more convenient than privately-owned electricity storage. Grid connection requires a conversion from direct current (DC) to alternating current (AC). This conversion also enables the use of standard AC supplied household equipment.

Many household appliances, however, work internally on DC. This implies the need for a transformer inside the appliance, in order to convert the AC current of 230 V to (low voltage) DC current. Using PV with an AC grid thus involves two energy conversions, with inherent energy losses. It is reasonable, therefore, to assume that introducing a DC (low-voltage) grid can mitigate these losses.

The feasibility of this idea has been studied by the ECN (Energy Centre The Netherlands) [1], by comparing a stand-alone PV-powered AC house to a stand alone PV-powered house provided solely with DC electricity. A conventional lay-out was used for both situations, with up to 40 meters of cable length. Their conclusion was that introducing DC would not lead to a significant reduction of energy losses. This result is, however, strongly influenced by the original assumption of a conventional indoor distribution layout.

2. OBJECTIVES AND SCOPE

The aim of this research is to investigate to what extent the energy losses in a PV-powered house can be mitigated by introducing a DC low voltage distribution system. The present study focuses mainly on two issues, which have been given relatively little attention in previous research:

- What if both AC and DC are used, so that higher power demands are met with AC, and lower power demands with DC electricity?
- Is it possible to reduce distribution losses by adapting the design of a standard house, so that the distances in the indoor distribution lay-out are limited? At present the power

losses in the DC low-voltage distribution system are high due to large distances in standard indoor grid lay-outs.

Differences in losses between DC/DC and AC/DC converters were also looked at in the present study, but to a lesser extent. Previous research by ECN did not take into account the losses at the supply side of household appliances.

The conceptual design of the DC system starts from a reference house, currently being planned for the 'Groene Kreek', a district in the city of Zoetermeer, The Netherlands. The reference house is being redesigned into a concept house, which is optimised to incorporate a DC distribution system, photovoltaic electricity generation (PV) and storage. No loss of comfort for the inhabitants is a sine qua non condition.

3. RESEARCH OUTLINE

In order to meet the above-mentioned objectives, the following items are studied. First of all, different sorts of solar panels are investigated and a choice of solar panel type is made. The amount of generated electricity is calculated based on the availability of sunlight in the western part of The Netherlands and on an assumed efficiency of 10% for the chosen panel. A study is also done on the suitability of household appliances to work on DC low-voltage current, in order to estimate the electricity demand (DC load) and the number of solar panels necessary to feed the selected DC appliances. Combining these data for supply (PV panels) and demand (DC loads) enables a rough estimate of the storage capacity, and a tentative choice of an electricity storage system. The storage system choice also considers the possibility to spatially integrate the electricity storage into the house.
The distribution system is looked at in more detail. This study focuses on whether clustered DC appliances and a different lay-out of the house can lead to smaller distances in the indoor distribution grid, and hence to smaller electricity transport losses. A design is made for a distribution system in a concept DC- house, and the transport losses are calculated for the optimised lay-out. Finally the transport and conversion losses in the DC house are compared to the losses in a standard AC house, and conclusions about the feasibility of the DC distribution system are drawn.

4. RESULTS AND DISCUSSION

4.1 Solar-energy conversion.

Solar-energy can be converted into electrical energy and into heat. Photovoltaic cells (PV) are used for the conversion into electricity. For the concept house, poly-crystalline silicon cells with an efficiency of 10 % are assumed. This technique is the best developed at the moment, and is affordable for consumer use. The panels are placed on the flat roof of the building, facing south at an angle of 45 degrees from the horizontal plane. It is estimated that 24 square meters of solar panel can meet demand and provide a small overcapacity, to make sure that electricity demand can be met also during bad summers.

For the electricity output, data [2] are used concerning the average daily sun radiation over a year, based on yearly averages, yearly and daily averages. With these numbers the electricity output for the 24 square meters of panels with an efficiency of 10 % is estimated. The results are shown in the next section together with the estimated demand. (see Figure 3)

4.2 Electricity demand in the DC low voltage house.

To estimate the DC and AC loads in the concept house, first the total electricity demand is assessed [3]. Average annual electricity consumption in the 'Groene Kreek' is estimated to be slightly higher than the average of 3500 kWh per year in the Netherlands. Based on the income levels of future inhabitants, average yearly consumption per household in the 'Groene Kreek' is estimated to be ca. 4000 kWh.

This is the total output for both AC and DC electric loads, regardless of which appliances can be supplied with low-voltage DC, and of how much they consume. The suitability for DC supply strongly depends on how electricity is converted. In principle, every appliance can be made suitable, but some groups of appliances are easier to adapt to DC electricity supply, or already function on an internal DC supply. The suitability for low voltages depends on the power demand of the appliance: only low power demands are suitable (< 150 W) to low-voltage, or else the losses in the distribution system will be too high (see section 3.3)

Table 1: overview of appliance suitability for DC low-voltage supply.

Kind of energy conversion	Examples	Suitability for DC supply	Suitability for low-voltage
Electric → heat	boiler, coffee maker	++	+/-
Electric → rotational or mechanical	Washing machine, fan .	+/-	+/-
Electric → sound and vision	TV, radio, CD player.	++	+
Electric → light	Fluorescent lamp, light bulb	+/-	+

The suitability of DC low-voltage supply is investigated for four different groups: [4] TV and video appliances; lighting; small kitchen appliances which do not generate heat; and appliances using batteries (e.g. electrical toothbrush, cooling appliances). The total electricity demand is found to be 2400 kWh for DC, and 1500 kWh for AC. This DC demand is used for the calculation of the required number of solar panels.

Whether DC electricity supply can actually lead to a reduction in energy conversion losses depends on the efficiency of DC/DC and AC/ DC conversion. If the chosen voltage level (24V) matches the voltage level needed by the DC appliance, no voltage conversion is needed. However, several household appliances work on different voltage levels, which implies a need for voltage conversion also with DC supply. A possible reduction of energy losses thus depends on the losses in both AC/ DC and DC/ DC converters. In this study, tentative measurements have been made of the AC/ DC losses in household appliances. Significant electricity conversion losses were detected but the evidence is not yet conclusive. For the losses in DC/ DC converters, information was obtained and compared from various manufacturers. The various data indicated an average DC/DC converter loss of ca.10 percent.

4.3 The DC distribution system

In the concept house proposed in this research, the DC electricity is transported by means of a low-voltage distribution system. This has to be done in a safe way, with as little losses as possible. The voltage chosen for the DC grid is 24 V, due to compatibility with most PV panels and storage systems. To transport the same power load as normal at this voltage, a higher current is needed. As a result, power losses are higher because of a quadratic increase of losses with current.

$$P_{loss} = I^2 * R \quad (4.3.1)$$

where P_{loss} *= power losses; I = current; R = resistance*

These losses can be reduced by lowering the resistance, which can be reduced by shortening the length of the distribution cables or enlarging the diameter.

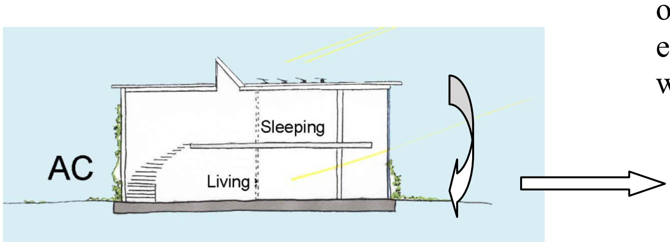
$$R = \rho * l / A \quad (4.3.2)$$

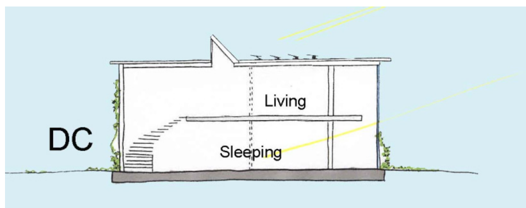
where l = length of cables; ρ = specific resistance; A = diameter of cables

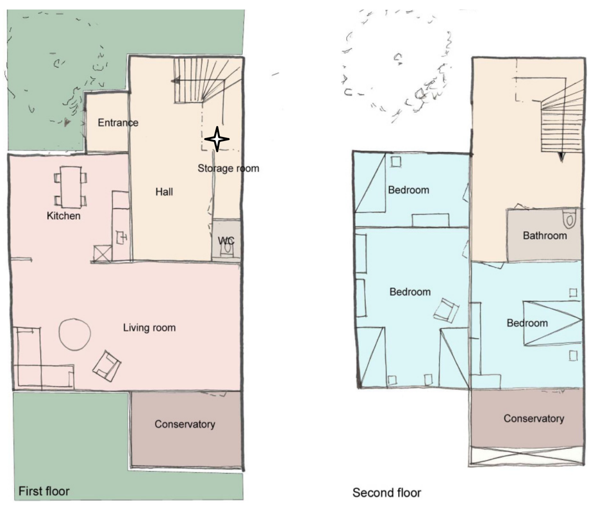
In this study, we investigate the possibility of reducing transport losses by shortening the length of electric distribution cables. The possibility of enlarging the diameter, perhaps even by a totally new electricity distribution concept, is not considered here. In this study, the spatial layout of the entire house is scrutinized and adapted so as to enable shorter lengths of indoor electricity distribution cables.

4.1.1 Building lay-out. The spatial layout of the concept house is adapted in this study, in order to reduce cable length and enable the use of DC, without loss of inhabitant comfort. Because the DC electricity source (solar panels) is on the roof, the rooms in the house are arranged so that the living room and kitchen (where most DC electricity is used) are placed closest to the source. This implies placing the living areas on the upper floor and the bedrooms on the ground floor, which is the opposite of a typical Dutch house layout. The intake point of cables from the solar panels is placed in the centre of the house.

Figure 1: Lay-out of the AC house, based on the reference house. The intake point of electricity (the meter cupboard) is marked with a star.







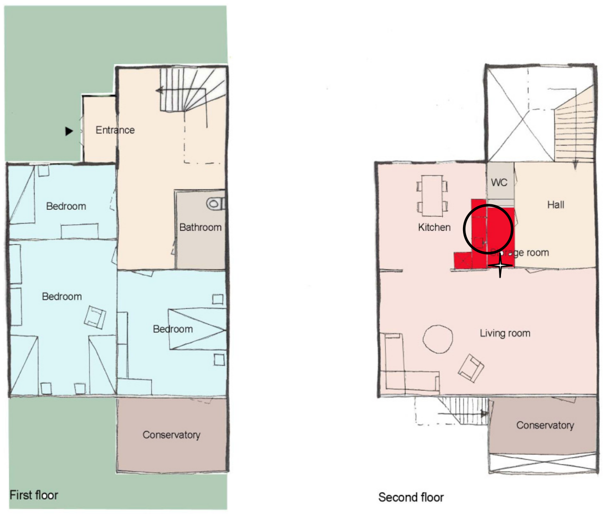
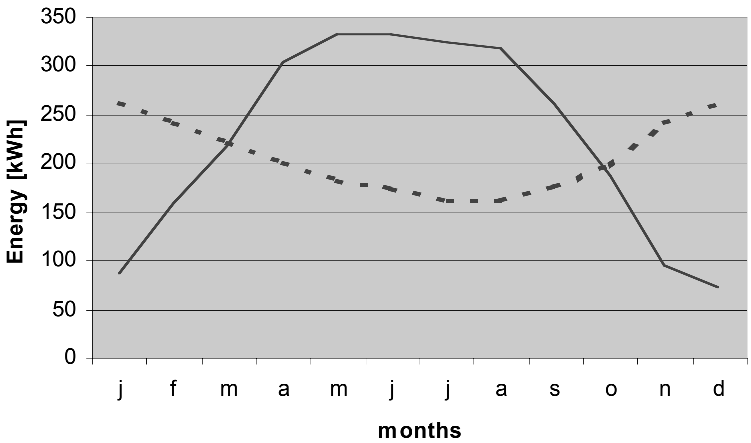


Figure 2: Lay-out of the DC concept house. The intake point of electricity is on the second floor, in the centre of the house. (marked with a star). Cirkeled is the zone where AC appliances are concentrated.

With this arrangement, and due to the placement of the electricity intake point in the middle of the house, cable length is reduced to a maximum of 12 meters, from the normal 40 meters in a standard AC house. Furthermore, all the AC appliances (mostly in kitchen and bathroom) are clustered in one single zone, so that an extensive AC grid is not necessary.
Furthermore, electrical installation plans are made for the DC concept house and for the reference AC house, to enable calculation and comparison of electricity losses in the distribution system.

4.4 Electricity storage

Since a stand-alone PV house is assumed, there is need for electricity storage. Storage systems suitable for usage in houses are flywheels, batteries and, if a good storage solution can be found, possibly hydrogen in the future. At this moment, lead-acid batteries seem to be the best option. In the future, lithium-ion batteries will form a cheaper and safer alternative. The required electricity storage system capacity is estimated in this study by comparing electricity demand from DC appliances (see section 4.2) and supply from the PV panels.



—— = electricity supply (25 m^2 PV panel, 10 % efficiency

.... = electricity demand (average 'Groene Kreek' house)

Figure 3: estimated yearly electricity demand and supply in the concept house [4]

A global estimate for a year-round storage system size can be made from figure 2. The storage system needs to cover ca. 600 kWh. This implies several cubic meters battery storage per house. Because of these large dimensions, another option is to cover only night time demand during the summer months (March until October), and use alternative power generating devices during the remainder months. This topic needs further research, but is not addressed in the present study.

4.5 Estimated overall system losses.

The relative losses in the whole system, from generation until end-use, are estimated for the DC low-voltage concept house and for the AC reference house. [4]

Table 2: estimated relative losses in the whole distribution system

	DC/ AC converter, PV → distribution	distribution system	AC/ DC converters in household appliances	DC/ DC converters in household appliances
AC house	8 %	0.5 %	Not yet available	0 %
DC house	0 %	4 %	0 %	10%

5. CONCLUSIONS

In this study, a mainstream reference house design is optimised in order to accommodate DC electric power distribution and generation with photovoltaic. An investigation into electricity demand by an average household, PV supply, DC distribution and storage clarified the following:

- The introduction of DC-based distribution has a potential to reduce conversion losses, by eliminating the need for conversion between PV and distribution (DC/ AC), and within appliances (AC/ DC).
- An essential condition for the realization of this potential is building design optimisation; in this study an improved house lay-out led to a significant reduction in electricity distribution losses.
- Another essential condition (not verified in this study) is that the relative losses in AC/ DC converters in household appliances should prove to be more than ca. 6 %. In this case, the total power losses in the AC house would exceed the total power losses in the DC concept house, so that introduction of DC based distribution would mean a reduction of the total losses of electricity conversion and transport.

6. RECCOMMENDATIONS FOR FURTHER RESEARCH

Further research is needed on the following topics:

- Losses in AC/ DC inverters in household appliances and in DC/ DC inverters
- Possibilities for new distribution networks, with larger cross sections and improved comfort (accessibility, flexibility, safety) for the inhabitants.

7. REFERENCES

[1] J. Pellis. 1998. The DC low-voltage house. Research by ECN (Energy Centre The Netherlands), Petten.

[2] KEMA, data on electricity consumption in new houses in VINEX locations in the Netherlands, based on enquiries. December 1996.

[3] Basisonderzoek Elektriciteitsverbruik Kleinverbruikers, BEK 1998. Energiened, Arnhem.

[4] M.M. Friedeman, graduation study report ‘the DC low voltage house’, TU Delft, 2002.