Update on DC voltage

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Residential and non-residential buildings

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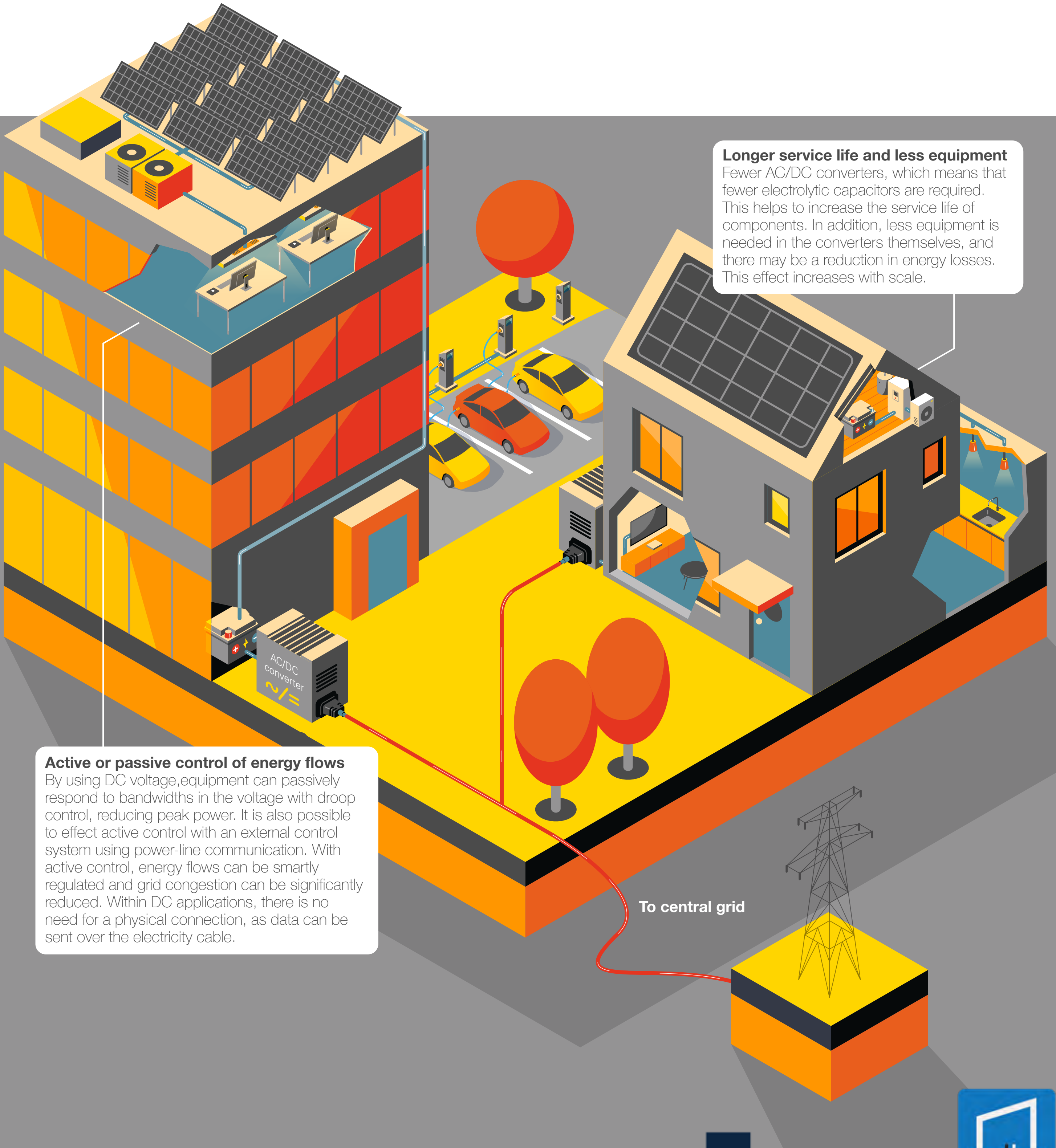

Berenschot
TKI URBAN ENERGY Topsector Energie
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DC voltage in residential and non-residential buildings

DC applications in residential and non-residential (business) buildings can reduce energy losses, save on equipment and simplify control of equipment—whether actively or passively. The potential benefit of this form of control is improved coordination with generation behind the meter and the prevention of congestion in the grid. The adoption of DC voltage in residential and non-residential buildings does face a number of difficulties, namely (1) standardisation, (2) safety and (3) incentives for consumers (building users and owners). It is recommended that the focus be on large-scale pilots, the development of certification for DC voltage components and the development of incentives for consumers. We look at these aspects in more detail below.

Background

This white paper is part of a report on the current state of affairs of DC voltage in the Netherlands. The report is an update of the DC Voltage Roadmap, which was compiled in 2018. General information and details about the benefits, drawbacks and challenges of DC voltage are explained in the appendix update on DC voltage. In addition to the update on DC voltage, we also look more closely at five specific market segments by means of five white papers. This white paper looks at the DC voltage applications in residential and non-residential buildings market segment. We will start with the concept, then look at the state of affairs, market adoption, difficulties and recommendations.

Introduction

This white paper looks at the potential role of DC voltage in the built-up environment. This link between DC voltage and the built-up environment emerges from a number of developments in DC voltage equipment and the fact that there is a need for control of equipment. This is much easier with a DC voltage grid.

In residential and non-residential buildings, the implementation of DC voltage can reduce energy losses due to the reduced need for AC/DC converters. Additionally, there is also the potential for savings on equipment (due to the reduced need for AC/DC converters). There is also the possibility of smart control of equipment via power-line communication. Another form of control is more passive and uses droop control, which passively influences consumption based on voltage limits in equipment. This form of control is necessary due to the growth in the number of electrical equipment as a result of digitalisation and the energy transition. This benefit will increase as decentralised electricity production and use increase.

There is strong growth in the number of applications using DC voltage. Within this, there are two major trends: (1) digitalisation and (2) the energy transition. Examples of digitalisation in which DC voltage is used in everyday devices are smartphones, tablets and laptops. Additionally, the energy transition means that more DC voltage technologies are being used in the built-up environment; PV panels supply DC voltage, for example, and electric vehicles are charged with DC voltage.

Furthermore, there are expectations that the number of home batteries (as a result of the large number of PV panels and the abolition of the 'netting scheme') will increase over the coming years. Batteries, like PV panels and electric vehicles, also use DC voltage. In a nutshell, the number of technologies that use DC voltage in the built-up environment is vast and is expected to increase significantly over the coming years. The current electricity grid operates with AC voltage, which means that all of these technologies need converters to work.

In addition to the proportion of electricity required for heating, the number of households using electricity for cooking is also expected to go up, which will mean that future evening peak demand for energy will largely be demand for electricity (a demand currently met by natural gas to a large extent). Capacity problems are anticipated if these trends continue as they have been doing, as the current electricity grid is not dimensioned for this demand. This would mean that the grid would need to be reinforced. DC voltage can offer a solution here. By connecting (many high power demand) devices to an internal DC voltage grid, there is the potential to reduce the power supplied to devices selectively, or to shut them off if an overload is detected, without the need for additional smart devices. Additionally, DC voltage allows more power to be transported over the same cable, reducing the urgency at which a cable needs to be widened (cf. the local DC voltage grids market segment).

This white paper distinguishes between four different scale levels (Figure 1).

1. At the lowest level, only **individual applications** use DC voltage— a USB-C hub is a good example. With this, it is possible to charge several smartphones or laptops without the need for a converter or adapter for each one. **Benefit: saving on equipment thanks to fewer AC/DC converters, control of energy flows—actively or passively, for individual devices for example (with power-line communication (PLC) or droop control).**

2. At the second level, a building has both an internal DC voltage grid and an AC voltage grid. Applications where DC voltage has greater potential are supplied with DC voltage, while the remainder of the building continues to be supplied with AC voltage. An example of this would be a home where the kitchen, PV panels, electric vehicle and/or batteries are connected to DC voltage and the remainder of the home is connected to AC voltage. **Benefit: saving on equipment for groups of DC voltage equipment, reduced energy loss and maintenance, passive influence on consumption by setting limit values within a group of appliances (e.g. coordination within the kitchen).**

3. At the third level, the entire building is supplied with DC voltage. The AC voltage from the distribution grid is converted to DC voltage in the meter box. Apparatus that cannot operate on DC voltage require an AC/DC converter at this level. **Benefit: possibility of connecting vehicle chargers, solar PV and home batteries with less equipment, reduced wear and fewer conversion losses, control of energy flows actively or passively between domestic appliances (with PLC or droop control).**

4. At the highest (fourth) level, a DC voltage grid is shared within a district or building complex. The difference between this level and level three is that here, part of the distribution grid must also be converted to DC voltage. **Benefit: connection to local charging infrastructure and generation with less equipment, less maintenance and fewer conversion losses. Active or passive control of energy flows within a district (with PLC or droop control), with the potential to reduce grid congestion.**

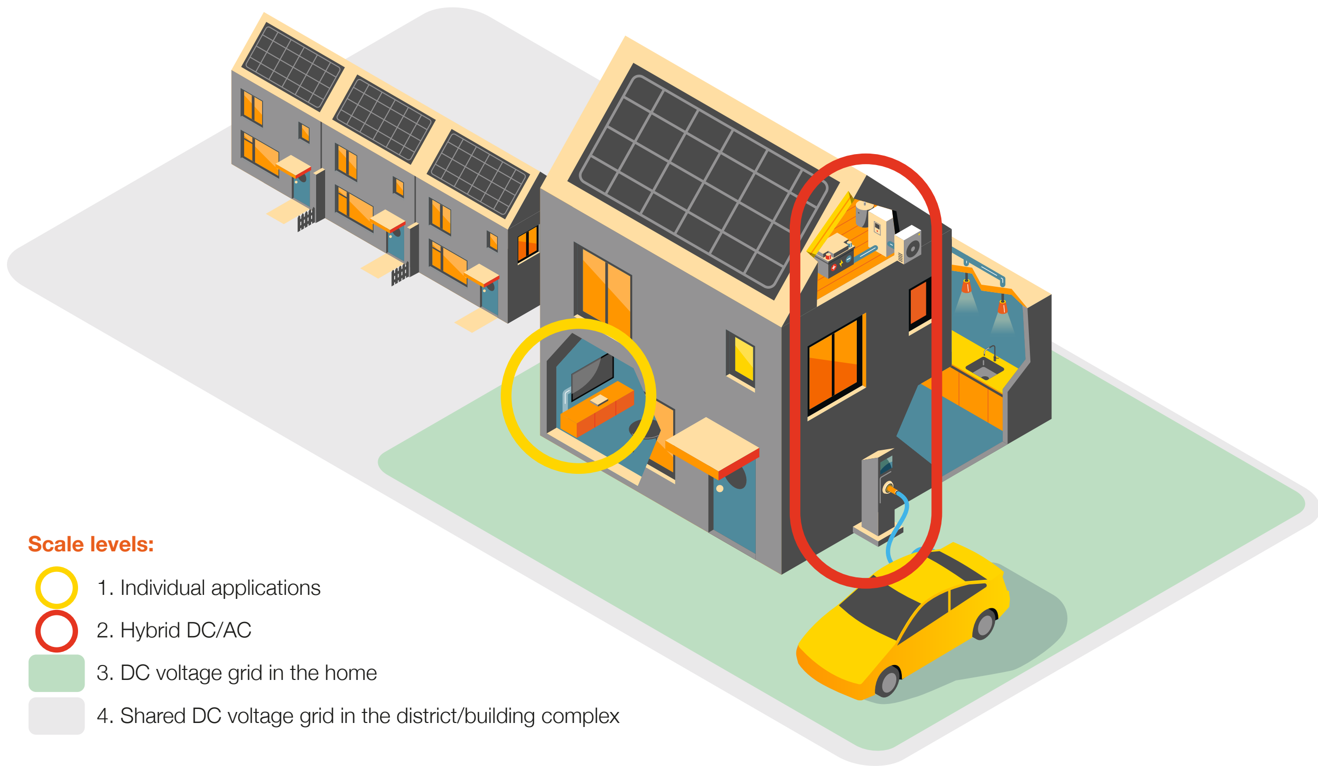

Figure 1 Visualisation of the scale levels of DC voltage in the built-up environment

Scale level	Opportunity	Complexity	Availability	New-construction
Individual DC voltage applications	High	Low	High	Not required
Hybrid DC/AC grid	High	Average	Average	Not required
DC voltage grid	Low	High	Low	Not required, complex yes
Shared DC voltage grid in the district/building complex	Low	High	Low	Required

Table 1 Scale levels of DC voltage in the built-up environment (1/5 = low, 5/5 = high)

Areas of overlap with other market segments

A grid for residential and non-residential buildings has a number of areas of overlap with other market segments. At a low scale level, it has consistencies with the charging infrastructure or public lighting market segments, chiefly because it is a grid (section) or installation dedicated to a single application. This makes the switch to DC voltage easier, as not all equipment needs to be adapted to work with it. Fewer AC/DC converters are needed, and it may be possible to control energy flows more smartly with PLC or droop control, either actively or passively. Another consistency here is the increasing amount of DC voltage equipment in society, a trend being driven by the energy transition.

At a higher scale level, DC voltage in the built-up environment bears similarity with a local DC voltage grid. This is primarily because of the multiple users on the grid and the fact that a section of the current distribution grid needs to be converted to DC voltage.

Current state of affairs

As indicated in Table 2, a number of projects are currently under way involving DC voltage in residential and non-residential buildings. The projects are being carried out within the different scale levels, with most projects currently in the demonstration and prototype phases.

At scale level 1, there are two projects looking at the development of DC voltage components to facilitate the application of DC voltage in residential and non-residential buildings. These projects are looking at the conversion of existing equipment and at the development of USB-C connections.

Additionally, there are several projects focused on hybrid options. In this regard, the integration of a DC voltage grid alongside an AC voltage grid is possible on different scales, such as homes and cold stores, or a specific production hall or roof. The DC voltage grids are used in these projects for the connection of DC voltage applications.

Two projects are looking at the implementation of solely DC voltage grids, such as at the education building at Delft University of Technology and in a 'proof of concept' project in innovative housing in Heerlen. The latter is known as the 'DC-Flexhouse' project, where the intended goal has not been achieved—although the technology developed in DC-Flexhouse and USB-C has been successfully applied in Circl and PULSE.

Project name	Project	Link to other technologies	Organisations	Subsidy	Type	Year (start)
DC voltage domestic appliances	Conversion of existing equipment to DC voltage	N/A	ABB/ATAG/DC opportunities/Direct Current/HHS/Simulation research/SGSN	Gas-free districts innovations	Proof of concept	2018
DC flexhouse	Five work packages for the replacement of energy infrastructure in residential buildings	District level (DC voltage grids)	ABB/Direct Current/IPM/HHS/IBC-Solar/Stichting Hogeschool Zuyd/SGNL	IDEEG2	Proof of concept	2015
USB-(D)C	Development and realisation of electrical connections for DC voltage grids for electronics, lighting and minor consumers		Direct Current/ABB/BAM/HHS	IDEEG2	Development and market introduction	2015
Smart DC lofts	Hybrid DC/AC grid in innovative houses in Eindhoven (Strijp-S)	PV/storage/district	Volkerwessels Icity/HOMIJ/ABB/Direct Current/Van Mierlo/OpenRemote	DEI	Demonstration	2016
ZoCool	Hybrid DC/AC grid for cold stores in the fruit industry	PV/cooling system/control system	DNV GL/AFI/Direct Current/Fruitpact/I-Thermostat/KEMA/Solar Comfort/Van Kempen Koudetechniek	SDE+ solar and built-up environment	Demonstration	2014
Pulse building	Energy-neutral education building at Delft University of Technology	PV/USB-C	DC Systems/TU Delft		Demonstration	2018
Stream acceleration project	Residential buildings in Soesterberg for zero-on-the-meter concept with DC voltage modules	Heat pump/ventilation unit/PV	BAM/Volkerwessels/Ballast Nedam/Dura Vermeer/Direct Current	STEP subsidy and FEH loan (for housing corporations and landlords)	Demonstration/prototype	2014
Factory Zero	Roof-integrated energy module for ventilation, heating and cooling using DC voltage	PV/plate boiler	Factory Zero	MMIP combination	Prototype	2020
Smart TinyLab	Investigation into a 350 V/DC grid in a residential building compared to an AC voltage grid in a residential building	PV/heat pump/storage/kitchen/lighting	Saxion/Eaton/Bouwschool Twente/BINX/BRControls/Dumont Advies		Proof of concept	2020
CASA project	TU/e research project into innovative housing construction of which a hybrid AC/DC voltage grid is a part	PV-T/lighting/heat pump/kitchen/(seasonal) storage	TU/e/Eaton/SolarTech/DUCO/NRGTEQ/HoCoSto/Geerts		Proof of concept	2020
Circl	Office building at the Zuidas on DC voltage	PV/lighting/ventilation/batteries/USB-C				2017

Table 2 Projects with DC voltage applications in residential and non-residential buildings

Market adoption

The 2018 DC Voltage Roadmap outlines timelines for the market adoption of DC voltage in different market segments. Figures 2 and 3 below show the timelines for DC voltage in residential and non-residential buildings. As indicated in ‘Existing projects’, there are several pilots and demonstrations for DC voltage in residential and non-residential buildings. Additionally, the application of DC voltage in residential and non-residential buildings is not yet market ready and would appear to be more complicated in residential than in non-residential buildings due to the high complexity of residential buildings. Consequently, market adoption appears to be following the anticipated trend of the timelines.

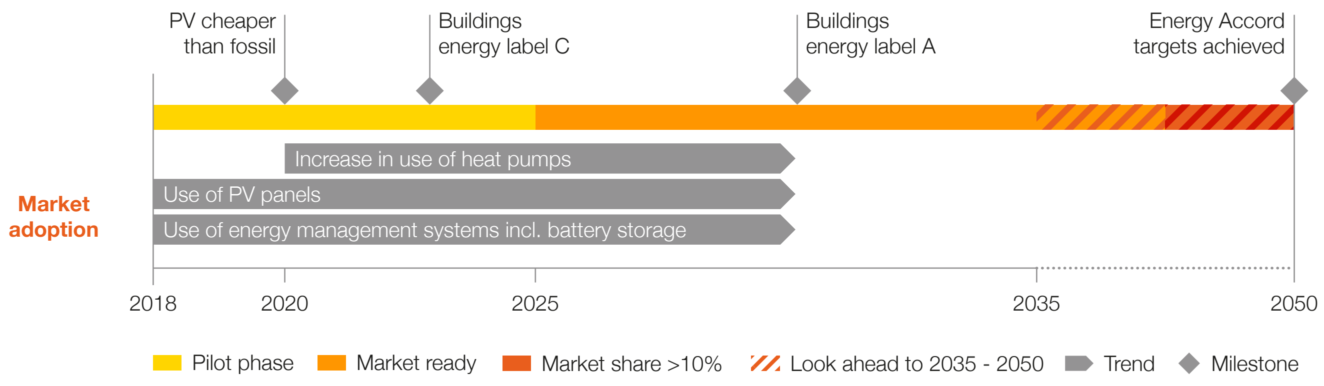

Figure 2 Timeline for non-residential buildings from DC Roadmap

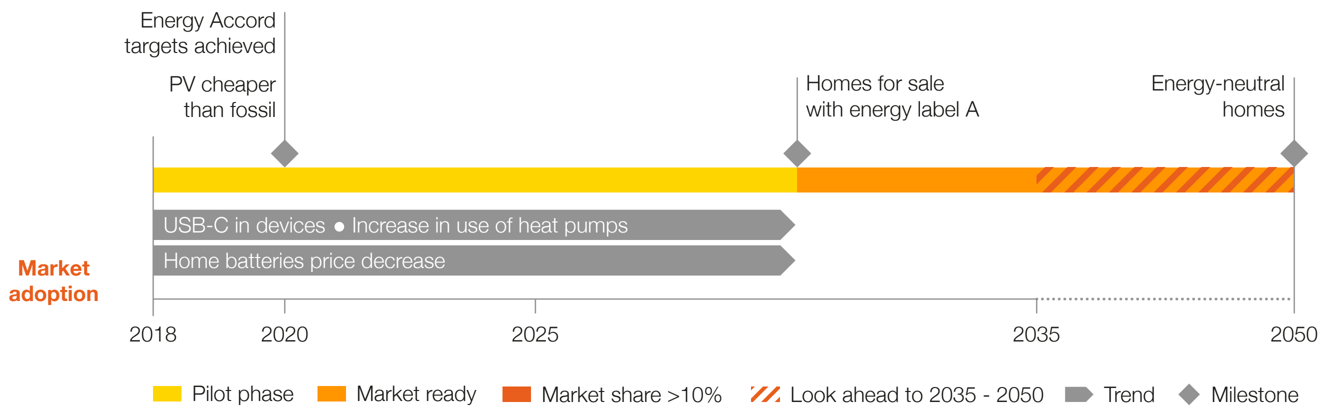

Figure 3 Timeline for homes from DC Voltage Roadmap

Difficulties

Standardisation, safety and policy create difficulties for the development of DC voltage in residential and non-residential buildings. These difficulties mean, for example, that DC voltage equipment cannot yet be produced on a wide scale for the built-up environment. The **availability of equipment is, therefore, limited**. To one degree or another, the difficulties occur at all scale levels. In terms of policy, there is a specific difficulty in terms of a legally established DC kWh meter. This particular difficulty is also present in the other market segments.

- **Standardisation (1)**
  There has only been limited development in terms of DC voltage equipment in the built-up environment when it comes to certification. For example, there is currently no CE mark for DC voltage kitchen appliances. Appliances cannot be sold without a CE mark, which means that there is no market demand. This stops manufacturers from producing DC voltage appliances, but also prevents them from researching such appliances at all.

- **Safety (2)**
  Manufacturers indicate that there is still too little testing of the safety of DC voltage equipment. Although there has been considerable research into safety through test setups and laboratories, there are not yet any practical projects involving DC voltage equipment in homes. Consequently, complete safety cannot be guaranteed. Although safety is an issue at all scale levels, it easier to resolve at lower scale levels. This requires the safety of only a single application to be demonstrated and certified, rather than a whole system where a combination of components must also be tested together.

- **Incentives for consumers (3)**
  A benefit of DC voltage is the controllability of the system. This is not yet an additional benefit for consumers: their appliances already work. Since consumers lack transparency as to which appliances consume a large amount of energy and which cause overloads, they will not be able to see the benefit of DC voltage in the current situation, while these benefits do exist at system level. Additionally, consumers are currently not paying more for higher peak demand, so there is no benefit to consumers for reducing peak demand. As soon as the ‘netting scheme’ for the feed-in of solar energy disappears, the controllability of electricity demand within homes will be of greater interest to consumers. This can be achieved with PLC (power-line communication) for example, where appliances can be controlled through an interface in the same way as with AC voltage, but with data over the cable. Another option offered by DC voltage is the use of droop control, where devices respond passively to the voltage level and automatically adjust the required power accordingly. If there is ample solar energy available, or too little solar energy, devices will be able to recognise it in the voltage and respond accordingly in the consumption.

Recommendations

DC voltage in the built-up environment can be implemented at various scale levels. with the lowest scale levels apparently more feasible in the short term. As a general recommendation, the difficulties should first be removed at the lower scale levels before focusing on development at higher scale levels. To further develop DC voltage in the built-up environment, there is a need for attention to large-scale pilots, the development of certification for DC voltage components and the creation of incentives for end users, such as price fluctuations during peak times.

- **Large-scale pilots**
  Most pilots looking at DC voltage in the built-up environment have been carried out in laboratories. There have been no pilots in residential buildings, so the exact benefit of DC voltage has not yet been fully quantified. The industry has indicated that there would be considerable added value in fully connecting one home to DC voltage and comparing it to an equivalent home running on AC voltage. That way, the added value of DC voltage when compared to AC voltage can be examined transparently, and DC voltage equipment can be tested in an everyday environment. Such a pilot can be carried out in the short term. More projects have been completed in non-residential buildings, but the benefits have not yet been clearly quantified.

- **Develop certification for DC voltage components**
  There is currently something of a ‘chicken-and-egg’ problem with the certification of DC voltage equipment for the built-up environment. Companies are unwilling to commit to DC voltage equipment on a large scale, as there is no certification for DC voltage equipment, yet there is no

certification because only a few companies are working on DC voltage equipment. Additionally, there is demand from various niches for DC voltage equipment for the built-up environment, but no such equipment is being delivered due to the lack of certification. It is therefore recommended that considerable effort be made to certify DC voltage equipment for the built-up environment. This certification can occur as soon as there are clear standards that can be used for certification by accredited companies.

- **Create incentives for end users**
  There are two ways in which users can be encouraged to use less electricity during peak times. This can firstly be done with passive droop control, where appliances automatically respond to the bandwidths in the voltage.
  It is important to create incentives that reward end users for setting up the system correctly, which could be achieved by introducing higher charges during peak times. The 'netting scheme' goes against this, because end users currently want to feed as much PV energy into the system as possible and have no incentive to compensate for this energy themselves using, for example, droop control with DC voltage. Secondly, there is the potential for incentives to be created for introducing smart control systems, where users can choose a cost-effective strategy in use. Here too, there must be an incentive by assigning a higher cost to electricity at peak times. Additionally, users should have insight into their real-time consumption.
  This second solution can also be introduced with AC voltage, but DC voltage has the benefit that data can be sent over the electricity cable using power-line communication (PLC) and no additional connection is required.