Smart buildings for smart grids

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Foreword

This report was drawn up following several workshops organised by TVVL. In these workshops the research topics were formulated and the scope of the investigation was defined. TVVL is very grateful to all members who contributed. The results of this report were presented during the New Year symposium on 10 January 2012.

Summary

In the context of this report, Smart buildings are buildings in which the energy housekeeping is optimised by an information network. This is aimed at minimising the cost of total energy used via the connection to the public electricity grid, or even converting this connection into a source of income.

This report consists of two parts. The first part covers the most important aspects of smart grids and smart buildings. The second focuses on energy supply techniques that can be used in buildings and which influence the operation of smart grids in smart buildings.

Smart grid technologies in buildings enable flexible energy housekeeping (e.g. peak shaving). A distinction can be made between energy production (e.g. CHP with a varying relationship between heat and electricity production), energy consumption (e.g.: interruptible demand) and buffering (e.g. batteries).

To provide an indication of the added value of the various techniques in relation to a smart grid a reference building was examined with respect to energy and costs savings produced by using these techniques. This is shown in Figure 1.

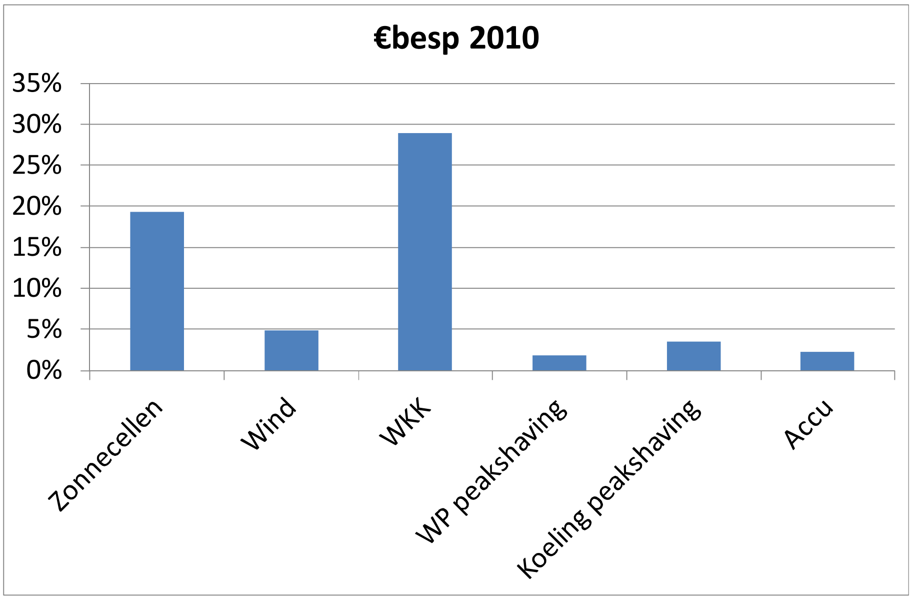

Figure 1: The impact of various smart grid measures on energy costs in the reference building.
[Translation: **Savings in euros, 2010;** Solar panels; Wind; CHP; Heat pump peak shaving; Cooling peak shaving; Battery]

Inhoud

1. Introduction

Traditionally our electricity networks have been laid out with large central generating units and many decentral units for which electricity consumption can be predicted within an acceptable bandwidth. This is about to change. In future our energy supply will be based on more local and regional (sustainable) energy generation and buffering capacity such as in electric cars. In addition the increase in the number of large energy users, such as heat pumps or electric cars will increase the load on the grid and reduce the predictability of this load. The increase in the load on the grid could cause problems in the short term. With the increasing unpredictability of the load, suppliers and the national grid operator TenneT will have to purchase more flexibility. As flexibility is expensive this could lead to higher energy prices.

There is also a need for increased flexibility at the international level. Wind energy from the North Sea, buffer capacity in reservoirs, hydroelectric power from Norway and in the future solar energy from the Sahara.

A smart grid offers a solution by making use of information and control systems to balance the demand and supply of energy.

This publication describes the various aspects of the smart grid from the perspective of the building. The publication consists of two parts. In part one, the smart grid is described in all its facets. Part two describes the various facilities in buildings that can have a relationship with the smart grid.

2. Why a smart grid?

The increasing sustainability of the energy supply is leading to developments that are currently not catered for by our power supply systems. These developments are briefly outlined in this chapter together with a discussion about the problems that could result as a consequence of these developments.

2.1. Developments

The main developments that relate to increasing sustainability are:

- A large increase in decentral energy production.
- The electrification of transport (electric cars) and heating (heat pumps)
- Cross-border opportunities, such as the use of hydroelectric power from Norway, buffer capacity in reservoirs in France and solar energy from Spain.

These developments are described in more detail in this section.

Decentral energy production

SOLAR

Solar panels are becoming less expensive and electricity is becoming more expensive. Currently the payback time for an investment in solar cells is about 10 years. Within the foreseeable future our own solar power will be cheaper than power from the grid. In addition solar cells are often easy to integrate into the built environment. The potential of (photovoltaic) solar energy in the built environment is significant. Figure 2 shows the development of the production of electricity from solar sources in the Netherlands over recent years. It is clear that electricity production from solar energy is rising steeply.

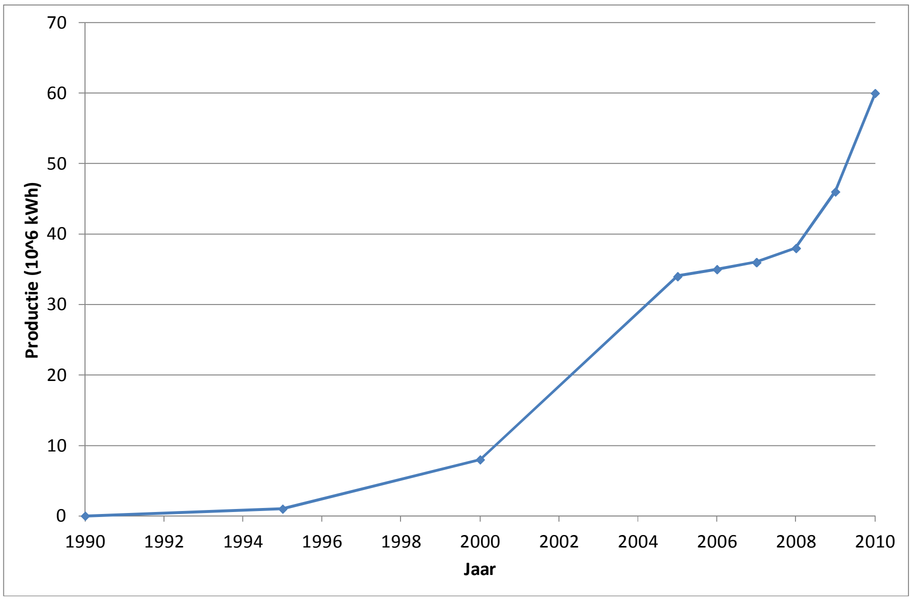

Figure 2: The development of photovoltaic solar energy in the Netherlands [1]
[Translation: Production; Year]

[1] Renewable energy in the Netherlands 2010 (CBS)

CHP

The use of combined heat and power (CHP – also called cogeneration) offers significant opportunities given the natural gas infrastructure in the Netherlands. The production of electricity where residual heat is also usefully used is very efficient. The environmental performance of CHP can be further improved by using biofuels and smart combinations with heat pumps. The installed capacity of (large) CHP plants is showing a robust growth, see Figure 3.

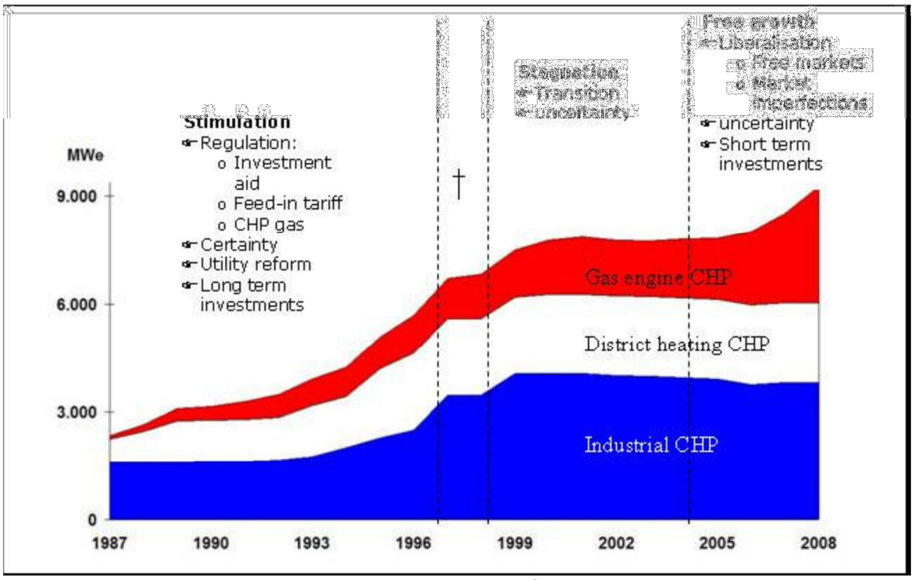

Figure 3: The development of installed CHP capacity in the Netherlands (Source: Cogen project; CBS; ECN)

The expectation is that there will be a significant development in the use of smaller CHP units. High-efficiency boilers that produce both heat and electricity will play an important role in this. These boilers are particularly suitable for the replacement market, which with approximately 300,000 units per year is a large market. Producers expect that around the year 2020 a million high-efficiency boilers will have been supplied, see Figure 4. Together, these boilers could supply a total of 1000 MW – as much as a large power station.

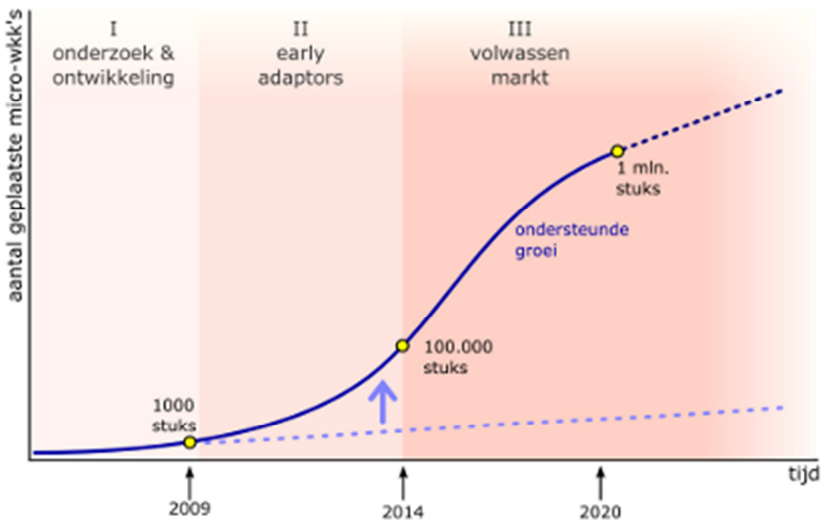

Figure 4: Suppliers' forecasts (source: www.microwkk.nl).

[Translation: Number of micro-CHP boilers installed; I Research & development; II Early adopters; III Mature market; 1000 units; Supported growth 1 million units]

It is also expected that the use of combined heat and power will increase in non-residential buildings, particularly in situations where there is a considerable demand for heat. Mini-CHPs are available from a capacity of about 5 kW.

WIND

The use of wind energy in the built environment is not generally considered to be very promising. Yields are relatively low due to poor wind conditions and the small-scale involved. However, there could be niches, perhaps precisely because of buildings making conditions favourable for the deployment of small wind turbines. The scale of such applications will remain limited. The use of wind farms on land locations that are wind-favourable is interesting, but often involves conflicting interests with nature, the landscape or industrial development. The number of offshore wind farms has been growing for several years. The expectation is that the production of offshore wind farms will substantially increase. Figure 5 illustrates the development of wind energy production in the Netherlands. A degree of stagnation can be seen, but it is expected that production will rapidly pick up again.

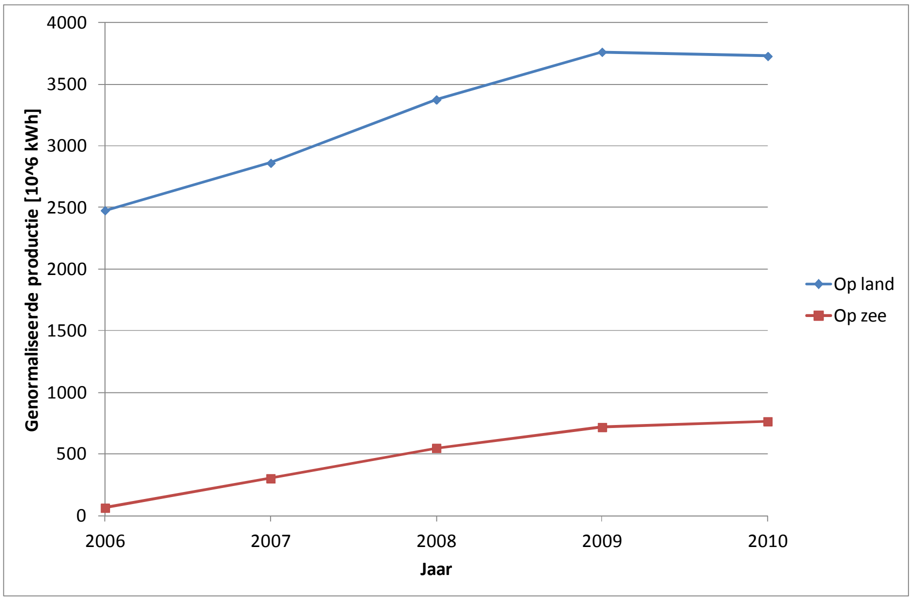

Figure 5: The development of wind energy in the Netherlands. (Source: Hernieuwbare energie in Nederland 2010 [Renewable energy in the Netherlands 2010] (CBS)

[Translation: Normalised production; On land; At sea; Year]

Electrification of transport and heating

Electricity is a very flexible carrier of energy. It is easy to transport and the use of electrical energy produces no emissions. Therefore future scenarios are often based on electricity as the main energy carrier. In applications where fossil energy has traditionally been used, replacements on the basis of electricity are increasing. The most obvious is space heating using the heat pump as an electrical alternative and in transport, where electric cars are being increasingly used.

Figure 6 shows the installed thermal capacity of **heat pumps** (using both air and ground as heat source). Figure 7 is shows the Dutch government’s forecast for the development of the market development for electric cars.

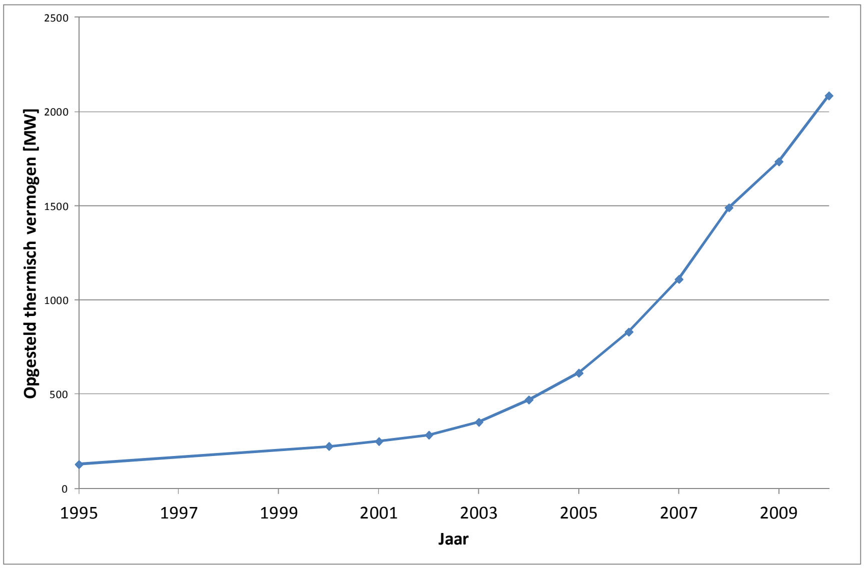

Figure 6: Installed thermal capacity of heat pumps in the Netherlands (Source: CBS, Statline)
[Translation: Installed thermal capacity; Year]

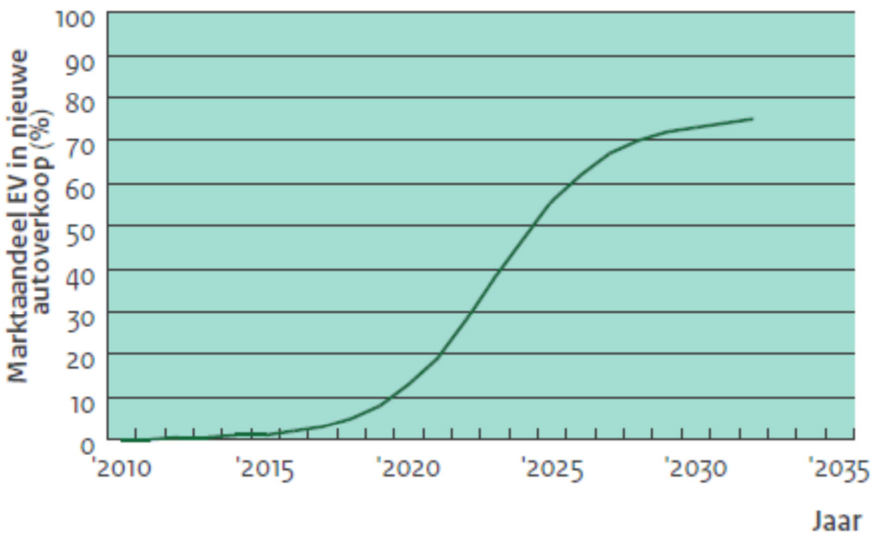

Figure 7: Dutch government's forecast for the development of the market for electric cars
[Translation: Market share of electric vehicles in new car sales (%); Year]

Cross-border opportunities

Norway has hydropower, wind energy is produced in the North Sea and Spain offers solar energy options. Making European energy supply more sustainable requires international cooperation. Figure 8 illustrates sustainable energy production in Europe in 2050. It is clear that each region is characterised by its own potential for sustainable energy production. These sustainable sources could complement each other effectively. This is shown in Figure 9.

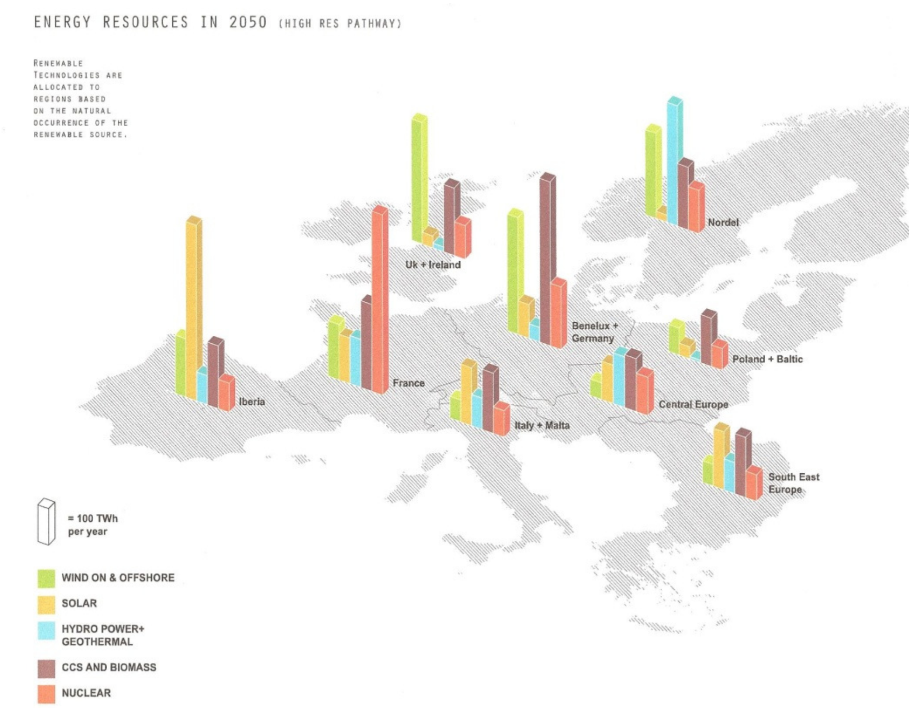

Figure 8: European renewable energy sources in 2050 (Source: Roadmap 2050, Office for Metropolitan Architecture, European Climate Foundation)

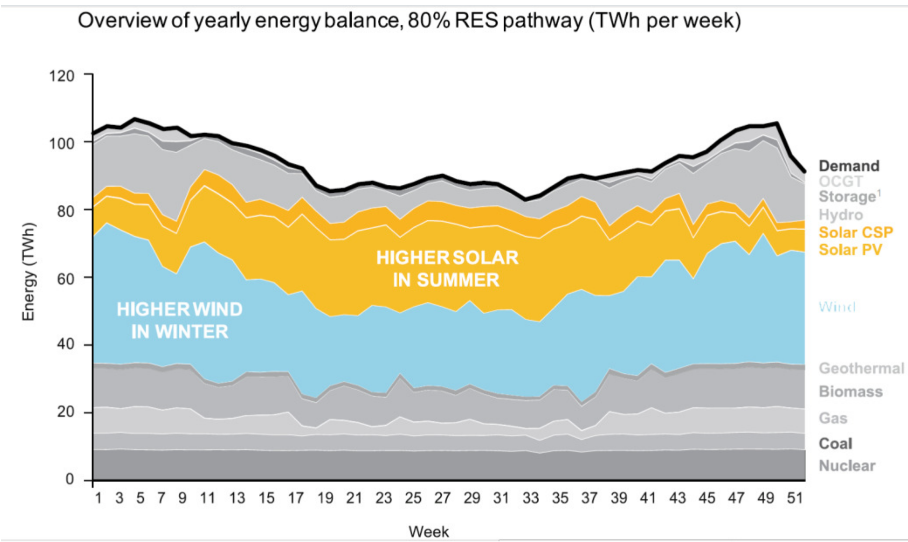

Figure 9: Vision of the energy balance in 2050. (Source: Roadmap 2050, Office for Metropolitan Architecture, European Climate Foundation)

In addition to these sustainable sources about 40,000 MW of large-scale storage capacity is available in Europe, particularly in the United Kingdom Norway, Italy and France.

The geographical distribution of the various sustainable energy sources and storage capacity make a European-wide intelligent super-network necessary.

Facebook to build servers at the North Pole.
The social networking site Facebook is planning to build a large green datacentre in Luleå, near the Arctic Circle in Sweden. Here the company will be able to benefit from access to sustainable energy and a cold climate, which is crucial for the cooling of servers. Luleå was chosen because of its climate and because it has the least expensive energy prices in Europe. The new data centre will be the largest in Europe. The server farm will cover 30,000 m², equivalent to 11 football pitches, and will handle the processing of all data from Europe, Africa and the Middle East. Facebook wants to build a green data centre to reduce its ecological footprint. 'It is our first data centre that will obtain energy mainly from renewable sources,' commented a Facebook spokesperson.

2.2. Limitations

The previous section indicated the developments that the electricity networks of the future should be able to facilitate. Considering these developments, today's networks are faced with a number of technical problems:

- The widespread use of electric cars and heat pumps will, without any further intervention, produce unacceptably high peak loading on the grid. This will be a problem for the grid operators. Also the simultaneous production of solar cells or high efficiency boilers could result in high peak loads on the networks;
- The widespread use of local energy generation could be detrimental to the electronic stability of the grid. This will also be a problem for the grid operators;
- The large-scale use of electrical transport and local power generation will make consumption less easy to forecast. The predictability of consumption is important for planning the deployment of large production units. Large plants are barely controllable.

The use of heat pumps in particular may give rise to problems in the short term. The expectation is that the other developments (electrical transport and local generation) may lead to problems in the longer term (about 15 years).

Peak loading

This increasingly heavy burden on the network, e.g. heat pumps and electric cars, could give rise to problems in the electrical infrastructure. The electrical power needed for a heat pump in a domestic house is 2 to 3 kW. In addition heat pumps are often equipped with reserve capacity for very cold weather. This reserve power is usually much larger than the power demand of the heat pump itself, thus increasing the load imposed on the network by the heat pump to 5 to 10 kW under extreme conditions.

The loading on the grid due to electric cars will depend on the type of battery and charging speeds. A car with a reasonably acceptable range will have a battery with a capacity of 25 kWh. To charge the battery will require a connection capacity of at least 3 kW. A normal charger (such as a charging station) has a capacity of 11 kW (3x16 A). Quick chargers (DC chargers), connected to the medium voltage grid can have a connection capacity up to 100 kW.

In the traditional situation (with a central heating boiler), the loading per house is approximately 1 kW. It is clear that the networks designed for this traditional situation will get into problems with the large-scale introduction of heat pumps and electric transport unless additional measures are taken.

Sustainable energy production is usually not easy to control. The supply of sustainable energy should also have priority over the supply of electricity from fossil fuel sources. Specific types of sustainable energy producers (e.g. solar energy, although the same applies to wind energy) tend to produce electricity at the same time. This can also lead to peak loading on the grid.

TenneT congestion management
It is already apparent that the available transmission capacity is insufficient in some areas. This is mainly due to the increasing decentralisation of energy production, such as offshore wind farms that have led to transmission problems in the Maasvlakte. TenneT has introduced a congestion management system to maximise the available transmission capacity. If there is a threat of the available transmission capacity being exceeded this system ensures that producers on this network are switched off. The reduced supply is then taken up by production capacity elsewhere in the country.

Quality

The quality of electricity depends on the extent to which the actual current and voltage characteristics of the system correspond to the desired characteristics. Poor quality is caused by power failure or switching activities on the network, which can lead to voltage dips. The quality can also be disrupted by specific customers who cause harmonic pollution or phase shifts.

The local generation of electricity can improve the quality of the service, because transmission distances are shorter. Voltage problems can arise in networks with large amounts of load and large amounts of power generation, especially if the generation is at low voltage. The need for electricity flow in two directions on the network and the added complexity of many small generating units involves complex balancing and can lead to fluctuations.

In the current electricity network the direction of the current is always clear. The current flows from a high-voltage network to a medium voltage network and then on to the low voltage network. In the case of the large-scale use of decentral generation the grid must be capable of working in both directions. When there are surplices on the low voltage network these can be sent to the medium voltage network. This requires the use of other techniques and security systems.

Specific control strategies will have to be developed to prevent these problems occurring.

Predictability and flexibility

The supply and demand of electricity must be in balance at all times. To plan the deployment of production units, the energy companies must predict the amount of electricity they have to supply the following day. This obligation is known as the program responsibility. The parties who make the programs are called program managers. Some (smaller) energy companies outsource their program responsibility to other companies. The National Grid operator, TenneT manages the planning and deployment of resources on the basis of all programs received from the program managers.

This plan never exactly matches demand. Reserve capacity is purchased to bridge the difference between planning and the actual demand. This reserve capacity relates to the deployment of both positive and negative regulating and reserve power and its deployment is expensive.

Not all production sources are sufficiently flexible to be adjusted quickly and accurately. For example coal fired power stations can barely be regulated. Large gas power plants are more controllable and the use of smaller production units (e.g. combined heat and power units by nurserymen) can be effectively controlled.

Power companies adjust their programs up until the last possible moment to avoid the need to deploy reserve capacity. This is done through bilateral contracts. Energy traded in this way usually has a higher price than energy purchased under long term contracts, but a lower price than the deployment of reserve capacity by TenneT.

The increase in decentral generation makes it more difficult to predict consumption accurately. There is a particularly large degree of uncertainty in the case of solar and wind energy, where the production depends on climatic conditions. Also large and unpredictable peak loading, as can be expected with the increasing use of electric vehicles will result in a higher degree of uncertainty regarding the expected pattern of consumption.

Increasing uncertainty regarding the supply offtake pattern results in a greater need for spare capacity and thus higher costs.

Control strategies can make use of buffers and interruptible capacity to ensure that the demand for electricity will remain within an acceptable bandwidth.

2.3. Conclusion

In this chapter we have discussed that some developments will have a major impact on the way electricity networks are used. We have also seen that today's electricity networks are not designed to handle this. These problems are expected to occur in the short term in the low voltage networks. In the medium-voltage and high-voltage networks this will only lead to problems in the longer term. The solution will be sought in intelligent control systems that will be able to balance supply and demand optimally.

3. What is a smart grid?

The previous chapter described expected developments as well as those aspects where the present electricity grid is considered inadequate to handle these developments. This chapter describes the characteristics of the grid that are expected to be able to cope with the developments.

3.1. Overview

A smart grid makes use of information and control systems to match supply with demand. Two-way interaction between energy users themselves and also with producers is essential.

A smart grid must have at least the following characteristic[2]:

- Flexibility: The ability to respond to the needs of users now and in the future.
- Accessibility: Enabling access to all connections on the grid.
- Reliability: Ensuring supply as well as delivery quality.
- Economic and efficient: Cost efficient, facilitating energy saving and energy management, ensuring a level playing field with respect to competition.

This creates opportunities for:

- Activating demand response from users, e.g. so that not everyone charges electric cars or turns on electrical equipment at the same time;
- Better integrating decentral generation and storage of energy into the system;
- Developing new products, services and markets linked to energy saving and convenience;
- Increasing the flexibility of the energy system;
- Reducing or delaying investment in networks;
- Guaranteeing the reliability of electricity supply.

The smart grid provides grid operators with opportunities to limit the power in their networks and suppliers the opportunity to supply the required flexibility in a cost-efficient manner. The smart grid also offers opportunities for end-users. The accessibility of the network to end users (in the future) will enable them to take full advantage of the dynamics of energy prices. End-users will be able to participate in energy production themselves and will be able to decide which producer they will receive their energy from. The expectation is that with rising costs, the increasing need for flexibility by the energy suppliers, and the increasing need for capacity control by grid operators this will become interesting for the end-users.

In addition to opportunities for demand-side management (generation, buffering and peak shaving), the smart grid provides a number of key elements behind the meter:

- The smart meter with the availability of detailed data per connection.
- Added intelligence at all levels.
- Microgrid.
- Virtual power plant
- Self-healing grid.

[2] European smart grids Technology platform, “Vision and strategy for Europe’s electricity networks of the future”,2006, Brussels

Figure 10: Illustration of a smart grid

These are described in the following paragraphs.

3.2. The smart meter

The current smart meter provides up-to-date information on the energy consumption of connections, status information about connected devices (up to five) and control signals (up to four) for connected devices. The term 'smart meter' is currently used to describe the future proof energy meters for small-scale users. The most important features of the smart meter are:

- Both energy supply and energy consumption are recorded (at intervals of 15 min). Incidentally the detailed data will in principle not be read by the energy companies and will remain in the meter memory for 10 days.
- The meter can be read remotely. Legally the meter may only be read once every two months without permission from the consumer. Only aggregated meter data is read, not the detailed data.
- There is a possibility that others (other service providers, ODAs/PESs) will have access to the data. These could be providing energy management services for example.
- The meter can limit the load using a threshold value.
- The meter measures the quality of the power supply and can send this information to the network operator.
- The meter can control apparatus or local energy production.

The technical specifications for smart meters are defined in NTA 8130. The term smart meter is somewhat misleading as the intelligence that actually determines how equipment and devices can be controlled is not contained in the smart meter itself.

The smart meter is aimed at small-scale users. Data from large-scale consumers with a connected load of more than 100 kW is already read using telemetry. These connections do not yet have access to the other options offered by smart meters.

To enable a connection to participate fully in the smart grid, more information and particularly much more intelligence is required. ECN has developed a protocol for the necessary additional intelligence under the name PowerMatcher. PowerMatcher can be the basis for a virtual power plant. PowerMatcher is described in more detail in Section 3.4.

3.3. The Microgrid

A microgrid is a section in the low voltage network that can function autonomously on a temporary basis. The microgrid contains energy production, sustainable energy production, buffer capacity and interruptible demand (such as heat pumps, electric cars, air conditioning etc). The scale is medium-large (up to a few MW of connected capacity).

Malfunctions in the parent network can be temporarily handled by the microgrid. Once the fault has been corrected the microgrid is then synchronised with the parent network. This increases the reliability of the network.

A microgrid may, but need not, coincide with a virtual power plant (see section 3.4). The microgrid can then be considered as a connection with a flexible load or flexible production.

3.4. The virtual power plant

Small-scale (sustainable) energy production units are typically embedded in existing electricity networks without active control or monitoring. In the case of large numbers of local production units, it is necessary to optimise production to prevent disruption of the network and to give priority to sustainable energy production.

Combining a large number of small-scale production units enables the formation of a large production unit that is more or less controllable. This is known as a virtual power plant. A virtual power plant need not be limited to production units. The aggregation of purchasing patterns can lead to an interesting proposition in the energy market.

A virtual power plant is therefore a group of distributed generating installations that together can provide an interesting proposition for the energy market. The proposition is determined mainly by the consumption and production flexibility that the virtual power plant can provide. The connections that together form the virtual power plant do not necessarily have to be located in the same geographical area. However if this is the case the virtual power plant can then coincide with the microgrid.

The virtual power plant introduces a new role in the energy market. The intermediary that aggregates purchasing and production of a widely differing range of connections and combines them into a marketable to product. The intermediary arranges the trading of energy and controls the portfolio on the basis of price incentives (or using other parameters).

ECN has developed software that can largely take over the duties of the intermediary. This software is called PowerMatcher. PowerMatcher matches supply and demand, based on much the same bidding principles as in the wholesale market. This process is scalable and can be fully automated by the use of software agents. A software agent is a software component that fulfils a specific role. The software agent represents as it were the interests of the respective role. The system distinguishes the following software agents:

- Local device agent: Connected to the device to be controlled such as a sustainable energy system or a system with interruptible demand. For example the price for which energy is purchased or supplied can be established at the level of the local device agent.
- Concentrator agent: Aggregates the information from the device agents and concentrates information into one buying or selling position.
- Auctioneer agent: Finally determines the price based on all positions of the concentrator agents.
- Objective agent: Determines on the basis of which criteria the trading takes place. If no objective agent is present the system strives for a balance of supply and demand in its own cluster.

Figure 11 illustrates the operation of PowerMatcher.

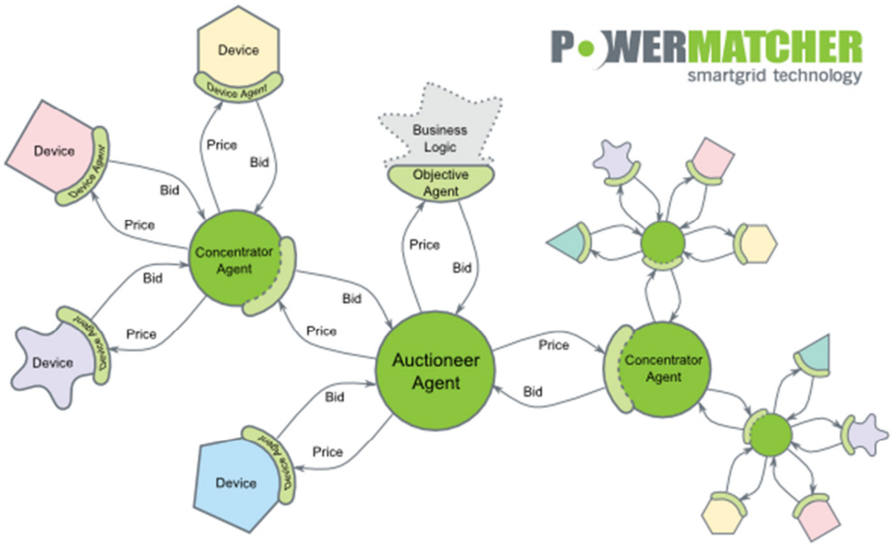

Figure 11: The operation of PowerMatcher based on different agents (Source: www.powermatcher.net)

3.5. The self-healing network

The self-healing network is an information and control system that can detect, localise and isolate defects in a network. Dynamic routing of the energy supply minimises the impact of defects in the network on end-users. The self-healing network increases the reliability of the system.

3.6. Changing roles

Fragmentation of the energy supply will cause roles played by the parties in the traditional energy market to change. Therefore the consumer will become actively involved (prosumer). The grid operator will also takes on a more active role, with a dynamic exchange of various data, smart control systems and flexible pricing. The energy supplier will utilise all opportunities to minimise the cost of unpredictable consumption and will possibly take on many other roles.

4. Scenarios in the Netherlands

Energy Report 2008, issued by the Ministry of Economic Affairs covers a number of possible scenarios for energy supply in the Netherlands in 2050. These scenarios are known as Powerhouse of Europe, Netherlands Energy Flexworker and Smart Energy City. These scenarios are further explained here (quoted from the report).

Powerhouse of Europe

The first school of thought is that the Netherlands could act as the Powerhouse of Europe. Due to the country's coastal location coal can be supplied easily and plenty of cooling water is available. Many more coal-fired power stations are planned in the Netherlands. In addition the gas infrastructure will be further developed into a gas hub, with a large number of gas generating plants. The flexibility of the system could be increased by opting for coal gasification. The Netherlands could provide base load power to its neighbouring countries, which would be responsible for providing their own peak power. The marine harbours would invest in handling capacity for coal and TenneT together with foreign partners would invest in the expansion of the network capacity to bring the power to the hinterland. Industry and particularly energy intensive industries would have everything they need. It is possible to make this scenario greener. The Netherlands could play an exemplary role in the capture and storage of carbon dioxide and the combustion of biomass, and is already working hard to develop wind farms on land and at sea.

Energy Flexworker

The second suggestion is that of the Netherlands as the energy flexworker of Europe. Increasing the scale of wind and solar energy plants will lead to a greater need for fast-start reserve capacity: generating plants that could quickly be switched to a higher or lower capacity. The Netherlands could deliver this Flex-energy – which has a higher value than base-load energy – thanks to natural gas. The countries around the Netherlands could take care of the base-load for North West Europe with their coal-fired power stations and nuclear plants. The Netherlands could develop into a flexible buffer between the 'must run' base-load and the highly variable forms of sustainable energy. Thus the Netherlands could trade its own (and in the future: purchased) gas for the best European prices in the form of electricity, and electricity supply would be the extension of the gas hub. This idea can also be linked to a green perspective, where the residual heat from the peak power stations would be utilised for new fishing industries (warm water fish farming) and the biofuel industry (oil extraction from cultivated algae). This fits in with a picture of the North Sea as an energy source, including the largest wind farm in the world.

Smart Energy City

The third vision is more locally oriented and concerns the Netherlands as Smart Energy City. The demand for less energy dependence in this vision leads to our own locally produced and often small-scale power generation (including solar, micro-CHP, manure digestion and solar water heaters). By making the electricity networks smart, the former energy consumers can become producers (they will be prosumers). With the micro-CHP and the smart meters as the starting point, decentral energy generation (where we are now the global leader) would continue to grow. Each household and business could have its own generation unit, with a smart network to cope with excess power. Dutch industry is specialising in increasingly smart designs with high added value (creative industry, trade and service provision) as well as a strong ecological profile (cradle to cradle). Once again this is a transition towards increasing sustainability, for example by using solar boilers, decentral energy storage in car batteries, or heat pumps.

0 Amp vision

The zero amp vision scenario is not included in the government's energy report. This vision was developed by Uneto–VNI. The essence is that the lowest possible power (preferably 0 A) will be present in all grids. As a result surpluses and deficits are always smoothed out to the lowest possible level. The automation of this concept is much simpler than that of the government's smart energy city concept.

The first two schools of thought relate in particular to the establishment of large-scale energy production in the Netherlands. The third scenario relates to the level of the low voltage networks and the zero amp vision and comes closest to the 'smart grid' as referred to in this publication. The different scenarios are not mutually exclusive, but provide a picture of the relevant development in the field of energy infrastructure.

5. What can and may happen on a smart grid?

The following sections discuss the constraints relating to the smart grid. Firstly we will examine the current legal situation and then the specific price incentives needed to persuade passive members to become active members.

5.1. Legislation

Energy supply and demand are optimally matched on the smart grid using smart control systems. This section discusses the constraints imposed by current legislation on the basis of a number of concrete questions. The content of this section is largely based on the report ‘Smart grid pilots, guidance for the enforcement of laws and regulations; Part 2’.

What are protected connections?

Connections are divided into small-scale and large scale customers. Small-scale users typically have a single connection with a maximum power of 3x80 A (approximately 50 kW). This does not just apply to consumers, as more than 90% of users are classed as small-scale.

Small-scale consumers are legally assured of energy supply and the supply of electricity to them is only allowed by suppliers who have a license.

Does the present tariff structure apply in a smart grid?

Smart grids benefit from a tariff structure that is as flexible as possible, allowing all types of incentives for production, consumption and consumption limitations. Tariffs are deregulated for large-scale users, but for the small consumer they may be limited by legal restrictions.
The law stipulates that the costs for the grid operator are settled by a capacity tariff. The capacity tariff is a fixed amount for the transmission of electricity, depending on the capacity of the connection. The structure of this tariff provides no incentive to balance consumption with available supply. Network operators in the Netherlands are bound by maximum tariffs approved by the competition authority (NMa). This limits the possibility of using tariff differentiation to influence the load on a network. Incidentally grid operators are entitled to set lower tariffs than the fixed maximum tariff.

Legislation requires that settlement for small-scale consumers is done according to the supplier model. This means that small-scale users receive an invoice from their supplier which covers both the tariff for the connection (including meter costs) and the price they have to pay the supplier for the amount of electricity they have used. This commitment comes at the expense of the desired degree of flexibility for small-scale users in a smart grid.

Only consumers pay transmission costs. Producers supplying to the high voltage grid are exempted; however producers are also users of transmission capacity. It is economically efficient if the tariffs for the transmission of electricity reflect the costs brought about by those connected. In that case there is an incentive to all parties involved to keep transmission costs as low as possible.

This also applies to the costs of high voltage electricity grids. These are charged to consumers on the distribution networks using the cascade principle. This means that the costs are distributed among consumers based on load flow data among consumers who are connected to the grid section in question and the grid section with a lower voltage level. A feature of local sustainable energy production is that it takes place close to the area of consumption, resulting in lower transmission costs. Users who purchase electricity from a source nearby cannot be rewarded for avoiding transmission at all voltage levels.

The large-scale users do not have the legal protection that small-scale consumers enjoy. Large-scale users can be supplied without a supply licence and the pricing of transmission is not legally regulated. There are also no barriers to prevent electricity from different suppliers being consumed at the same time in a particular period.

Who may exploit an electricity network?

Initiatives that enable electricity networks to be operated by others than the grid operator fit in well with the smart grid ideas, e.g. a jointly-developed business park, or a residents association in a neighbourhood striving for autarky. However options within the current legislation are limited.

The task of the network operator is to provide sufficient transmission capacity by constructing distribution networks. These networks may in principle be constructed by companies other than the operator. The development of private networks would appear to be a difficult issue from a legal standpoint. The government has so far been very reluctant to grant waivers. The following grounds for granting exemption are stated in the Electricity Act:

- The network is intended to provide the applicant with electricity to support the applicant's central business process, or;
- The network is intended for a number of cooperating individuals or legal entities to provide electricity, with the goal of providing this cooperative with a reliable, sustainable, efficient and environmentally sound energy system in their establishments, or;
- Regarding the quality requirements, these should be significantly different from the usual quality standards required for an electricity transmission network, and;
- The applicant shall not be a (public) network operator and not part of a group of companies that includes a network operator.

In addition the following restrictions can be deduced from exemptions granted:

- The area involved must be geographically restricted.
- The number of members should be limited to at most a few dozen.
- At least 50% of the (legal) persons to be connected to the private network must be known at the time the of the application for exemption.
- The applicant must be able to put forward a sufficiently convincing argument in favour of the benefits of a private network compared to the public grid. A cost benefit on its own will not be considered an acceptable reason for granting an exemption, although it can be taken into account as an additional reason.

In the case of an installation where the electricity is supplied to the persons who are exploiting the installation at their own risk, the network is considered to be an installation rather than a public network. This installation does not necessarily have to be located on the premises of the consumers. Supply to joint-operators of the installation may take place without a license. Supply to other small-scale consumers may not take place without a license.

In a case where there is a network that supplies energy to several buildings in which the buildings and the electrical installation are owned by one owner, this owner may manage the energy generation unit.

The responsibility of the network operator for the reliability of the networks can make network operators reluctant to develop smart grids.

Network operators may not develop competitive activities unless necessary for the exercise of their legal task to ensure security in the network.

Network operators may not produce, trade or supply electricity, but they may purchase electricity to compensate for network losses. Network operators could, in principle,

purchase compensation for these network losses from small-scale consumers who are themselves producing electricity. Small-scale consumers/producers do not need a licence to supply.
Network operators are legally responsible for network management tasks. They are responsible for the reliability of networks and they are obliged to connect anyone who asks. They have a natural monopoly. It is possible that advanced techniques will make this natural monopoly obsolete. It is not obvious that the ICT system that is part of a smart grid should be part of this natural monopoly.

Who may trade electricity?

The production and trading of electricity are deregulated. The supply to small-scale consumers is protected. Only parties with a supply licence may deliver to these users. There are a few exceptions, such as the supply of electricity from your own facilities.

A supplier licence is in principle not suitable for small-scale consumers (or limited groups of small-scale consumers who are united in a virtual power station for example). A licenced supplier is obliged to supply any domestic consumer who requests electricity. Given their limited production capacity, domestic consumers or groups of domestic consumers will be unable to comply with this requirement. For the small-scale consumer/producer the options for selling self-produced energy to other small-scale consumers are extremely limited. Supplying energy to customers who are not protected is possible. Therefore the small-scale energy producer can sell energy to other suppliers, or to the grid operator who needs to purchase energy to compensate for network losses.

In principle the legislation governing electricity allows everyone, including small-scale consumers, to participate in the APX. However, the operator of this energy exchange has drawn up general terms and conditions that may be a hindrance for small-scale consumers. For example specific financial guarantees must be established.

The balancing & settlement regulation is used for small-scale consumers with their own production facilities. These small-scale producers will sometimes use their self-generated energy and sometimes wish to supply it to the grid. The balancing & settlement rule means that on an annual basis the electricity supplied to the grid may be offset by the amount of electricity they have consumed. This makes it unnecessary to draw up a separate contract for the supplies to the grid. The balancing & settlement rule usually only applies if the amount supplied to the grid is less than 5000 kWh.

Network operators supply only balanced and settled quantities to the supplier. Therefore the supplier does not know what has been produced. If a smart meter is available the supplier may also access consumption and production details (after obtaining permission). The balancing & settlement rule makes the financial compensation for feed-in electricity equal to the cost of purchased electricity. In principle this is beneficial to the participant. Balancing & settlement is based on a non-variable energy price (except in the case of day/night tariffs). This limits its use in smart grids. The balancing & settlement rule does not apply to large-scale consumers.

Who has the relevant information for operating a smart grid?

In the local distribution network the network operator is the hub of information traffic. The operator collects data from the smart meter and issues it to the supplier. These data do not relate to a period of less than one day unless the small-scale consumer has given explicit permission for this. Data may also be made available to third parties following explicit permission from the small-scale consumer/producer.

A network operator can only supply its services (including the exchange of information) to a consumer/producer with an EAN code. Connections within a private network fall outside the regular flow of information.

Who can benefit from balancing?

Supply and consumption must be in balance at all times in an electricity network. Section 2.2.3 elaborates on the role of those responsible for maintaining system balance. The system of program responsibility and balancing is interesting because the prices for reserve power are relatively high.

In principle, all those connected (both consumers and producers) have program responsibility. The law transfers the responsibility of small-scale users to their supplier. This limits the small-scale user's ability to trade flexibly. On the other hand it eliminates the risk of fines that could be imposed by TenneT due to program deviations.

Feeding-in electricity to the grid for balancing purposes to a supplier other than to your own is not logical.

The program responsibility of large-scale consumers is not transferred automatically. In practice it is outsourced and the financial conditions for this are negotiable.
Producers play a major role in maintaining the balance in the network by switching supply on and off for a market price determined by TenneT. In the case of large-scale integration of local energy production, maintaining a balance is really a local matter – maintaining the local balance. Activities involved in balancing the network are now reserved for TenneT (the so-called system services). In a distribution power supply there will be a need for additional balancing activities in the low voltage transmission network.

5.2. Price incentives

If there is no incentive to actively participate in the smart grid then this participation is unlikely to take place.

The following aspects are relevant when specifically looking at the added value of active connections in the smart grid:

- The reduction in your own energy consumption.
- The reduction of network losses due to more local exchange of energy.
- Avoiding the need for network reinforcements by using adjustable power.
- Electricity trade in the day-ahead market (APX).
- Electricity trade in bilateral contracts. These are contracts with energy suppliers on an even shorter term than the APX. The energy suppliers (or actually the program managers) buy or sell power to prevent the deployment of reserve power by TenneT.
- Trade of electricity in reserve power. Reserve power is used by TenneT on the basis of an auction system as the load on the network deviates from the programs of the energy suppliers.

Under the current tariff structure, connections cannot make use of all of these added value options. The previous section describes how the present tariff structure (in particular the protected connections) does not correspond with the requirements of a smart grid. The following bottlenecks can therefore become an issue:

- Transmission costs are incorporated in a capacity tariff that is not flexible. The shifting of electricity load or the feed-in of electricity under the present tariff structure has no value in relation to the transmission costs. This for example while a shift of load can represent a significant value if it is taken into consideration that this avoids reinforcement of the grid.
- The cost of operating high voltage networks is recovered via the capacity tariff using a cascade system. Local connections with energy production actually limit

the use of the higher voltage networks. This benefit is certainly not reflected in the pricing.

- Large producers (connected to the high voltage grid) are exempt from transmission charges. Transmission costs are therefore almost entirely transferred to those connected to the low voltage networks (both consumers and producers). Producers are also users of transmission capacity, thus imposing transmission charges on large-scale producers would provide incentives for local generation.
- Small-scale consumers have only a few options for the free trade of the energy they produce at variable rates. For example they cannot sell to other small-scale users.
- Those connected can only make limited use of the financial possibilities of offering reserve capacity. Small-scale consumers can only do this through their own energy supplier.
- The balancing & settlement scheme in which sustainable energy production and consumption by small-scale users can be settled does not take account of the different times that energy is produced. The use of pricing dynamics for feed-in by small-scale users is not possible.

What the actual pricing dynamics will be when the present grids reach their limits cannot be predicted. There are likely to be incentives aimed at greater pricing dynamics for both transmission and supply. Transmission costs will be more important for small-scale consumers than for large-scale consumers for whom transmission costs are relatively low compared to consumption costs.

The prices on the APX-ENDEX give a reasonable picture of the movements in electricity prices. Figure 12 shows the APX electricity prices, indicating that in 2008 prices were rather turbulent and relatively high. Figure 13 shows the imbalance pricing and it is clear that the costs for the settlement of imbalance are much higher than the usual APX rates. The imbalance volumes are much lower than the volumes traded on the wholesale market. The average imbalance costs per (small-scale consumer) are about €10.

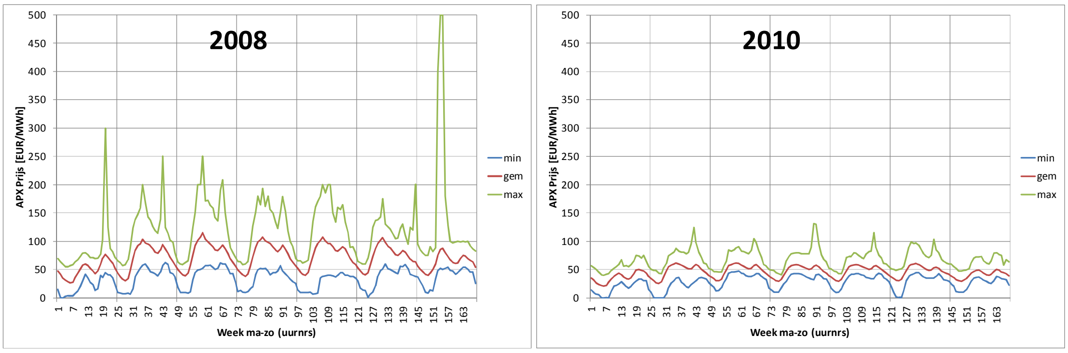

Figure 12: Course of APX price during the hours of a week in 2008 and 2010 (Source: APX-ENDEX)

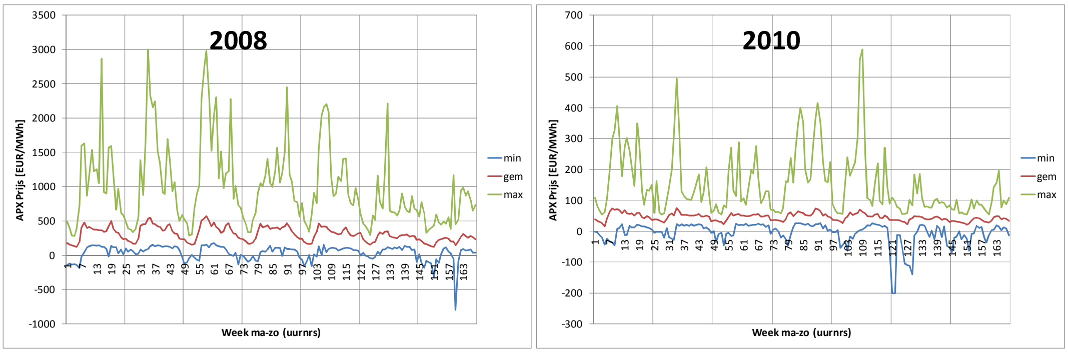

Figure 13: Imbalance pricing during 2008 and 2010 (Source: TenneT)

5.3. Participation

As a building owner you can participate in the smart grid through the use of local energy production, offering buffer capacity or actively influencing your consumption pattern. Participation in the smart grid will be encouraged by price incentives. These price incentives can be stated in a contract with the network operator or the supplier or any other party. It is expected that the financial returns will be too small to make it worthwhile participating in the smart grid on an individual basis.

The following forms of contract are possible:

- A fixed tariff system with rates differentiated by time.
- A maximum amount of power with penalty clauses for exceeding this amount.
- Making interruptible demand available on request, for example for a maximum duration.
- Making production capacity available.
- Making buffer capacity available.

All measures that contribute to a favourable purchasing profile can contribute to a smart grid. The various types of measures are given in Table 1.

Table 1: Type of smart grid measures

Type	Description
Energy saving	Taking energy saving measures can decrease the load on the grid.
Energy production	Switching on energy production at the correct time or feeding-in the energy produced to the grid rather than using it yourself.
Buffering	The buffering of energy can achieve a shift in the consumption pattern.
Interruptible demand	For some energy consumers the time that the power supply is switched on is not so important. The time can be chosen to be favourable for the consumption pattern. It is possible that switching off power supply to a consumer within an acceptable bandwidth will be at the cost of convenience.
Synergy	By combining different consumers it may be possible to obtain a more favourable consumption pattern. The maximum load for both users together will be smaller than the product of each maximum load separately.

Concrete examples of these types of smart grid measures will be given in part 2 of this publication.

PART 2

6. Introduction

Building owners can participate in the smart grid and the conditions for this will be that it is made legally possible and the tariff structure makes participation worthwhile.

Considering the connection there are two options: Energy production and flexibility.

The purpose of these measures should be to compensate surpluses and deficits in the network. Flexibility is the degree to which the pattern of consumption can be influenced. It is possible to differentiate between sustainable energy production and energy production using fossil fuels. Sustainable energy has the highest priority and it might be thought that it is not possible to influence it. However sustainable energy production does belong to the smart grid because one of the goals of the smart grid is to facilitate local sustainable energy production. Energy production from fossil fuels can be deployed when needed (i.e. it is flexible).

Regarding flexibility, we can distinguish between interruptible (or, perhaps better said postponable) demand and buffering capacity. Functionally they do resemble each other. In principle neither is associated with energy saving, but will only enable a shift in consumption patterns. A fundamental difference is that in a buffer, surpluses in the network can also be stored, or can also be delivered to the network. Occasionally interruptible demand goes hand-in-hand with energy savings. In that case it is at the expense of convenience, e.g. a refrigerator that is turned off temporarily. Interruptible demand is often tied to certain conditions. The switching on of the heat pump in a well-insulated building could easily be delayed for a couple of hours without causing problems, due to the buffering effect of the building's thermal mass, but shifting over an longer period may cause problems.

Table 2: The contribution of the various smart grid devices towards eliminating surpluses and deficits on the network

		Deficit on the network	Surplus on the network
Energy production	Sustainable	+	-
	Fossil	+	-
Flexibility	Buffer	+	+
	Interruptible	-	+

Saving energy also contributes to the objectives of a smart grid. In most cases, energy-saving measures will be even more profitable than the facilities described here. In general it will be most efficient to first exhaust all possibilities in the field of energy saving before participating in the smart grid. This publication deals specifically with smart grid measures related to local energy production, or with providing flexibility.

All actions 'behind the meter' that relate to changing or modifying energy use including changes to the consumption pattern are called demand side management.

7. Smart buildings for smart grids

If a building owner wishes to make use of the benefits of the smart grid, the technical (ICT) infrastructure in the building must be suitable. This infrastructure consists mainly of:

- Connection to the grid that allows feed-in.
- Control information (external or internal), such as pricing incentives.
- Separate metering of supply and feed-in for the connection (main meter);
- Information from components that can be controlled (generation, buffering and switchable power).
- Control of controllable components.

This is shown diagrammatically in Figure 14.

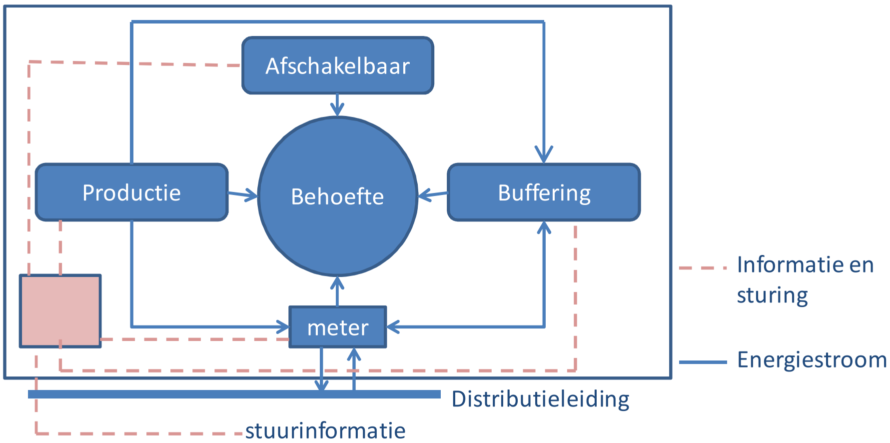

Figure 14: Overview of smart grid in the building
[Translation: Interruptible; Production; Need; Buffering; Meter; Information and control; Energy flow; Distribution mains; Control information
]

There are various protocols for information exchange with which an internal smart grid can be equipped. There is as yet no standard for the exchange of information outside the building. There is some standardisation work taking place in this area at the European level.

7.1. Measures

A number of measures or features that can be installed in buildings are described in the following sections. Indicators are given for the measures that give an idea about the value of a specific feature in a smart grid. The values relate mainly to the degree to which a measure can restrict loading or peak loading of the network. Electricity prices on the APX exchange are a good measure of peak load. At high loads prices are high and at low loads prices are low.

Value of a feature

The value of a smart grid feature has two components:

- The flexibility value relates to the shifting of consumption periods. For example a battery can be charged at a time that electricity is inexpensive and discharged when electricity is expensive.
- The value of (local) produced or saved energy relates to the commodity itself.

The value of flexibility is determined by the price differences. The commodity value is determined by the price of electricity at the moment that it is produced (or is saved). The value of the flexibility will generally be lower than the commodity value. This also indicates that the value of energy-saving or sustainable energy production is generally much larger than measures which only influence the consumption pattern.

APX trading prices are used to quantify the value of the facilities in the smart grid. The APX price is also a good indicator of the degree of loading on the network. If the loading on the system is high, the APX prices are usually also high. The APX prices may vary considerably from year to year. For this study the prices of 2008 (a year with many price fluctuations) and 2010 (a year of relatively stable prices) were used.

Facilities such as solar cells or interruptible demand can always be displayed as a pattern. The grid operator sees this pattern at the connection points of this facility, or the difference from the 'normal' consumption pattern. This pattern can be both positive (more supply by the grid operator) or negative (less supply by the grid operator). For a facility that is mainly characterised by flexibility, this pattern has periods when less is supplied and periods when more must be supplied. For a facility that is characterised mainly by production or savings, this pattern only has periods when less is delivered (or less fed-in).

A weighted average APX rate can be determined on the basis of this pattern. This price is the value of this feature in the energy market. The following indicators are always given for each measure:

Van elke maatregel zijn steeds de volgende ketngetallen gegeven:

- APX price unweighted: The average MWh price, without weighting based on a consumption pattern (i.e. a smooth pattern).
- APX price for building: The average MWh price based on the consumption pattern of the building without the feature.
- The APX price for the building with the feature: The average MWh price based on the consumption pattern for the building with the feature. This is independent of the savings due to the feature (e.g. solar cells). The lower this price is the more efficient the feature.
- The APX price for 1 MWh (for energy production): The average MWh price based on the pattern of only the feature (i.e. without the building). Thus this is not dependent on the *volume* of production, but on the profile of the production. The higher the price, the more efficient the feature.

These calculations are not based on the current tariff structure. The calculated costs savings are not feasible with the current tariff structure, but are based on the dynamics of the prices of the day-ahead trading market.

Reference building

These calculations are not based on the current tariff structure. The calculated costs savings are not feasible with the current tariff structure, but are based on the dynamics of the prices of the day-ahead trading market.

APX 2008	78	EUR/MWh
APX 2010	49	EUR/MWh

The calculated costs savings always refers to the total energy use, so to both electricity and natural gas.

Graphical representation

A chart of the effect of the feature concerned on the consumption pattern is continuously recorded in the reference building. The basis for the consumption pattern is the standard consumption profile for business users, which is also used in the energy market for the trading of electricity. In this graph the resulting pattern is also shown for when the feature in question is in use and the difference between the two. In the example shown in Figure 15 the average effect of the contribution from the sun is shown. The green line shows the average electricity production by solar cells.

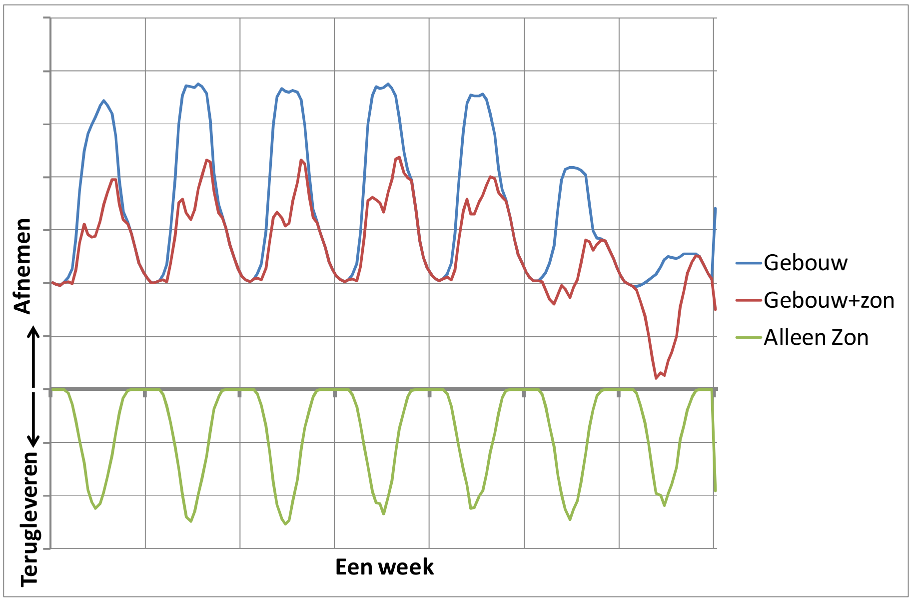

Figure 15: Graph of the impact of the feature on the consumption pattern
[Translation: Consumption; Building; Building + sun; Sun only; Feed-in; One week
]

8. Energy production

For local energy production we differentiate the energy generated by Solar panels and wind energy as sustainable forms of energy production. Energy can also be produced locally using the various combined heat and power options.

8.1. Solar panels

Description

Solar panels are ideal for local sustainable energy production. They are easy to integrate in both existing and new buildings.

Figure 16: Solar panels installed on the roof of a building

Smart grid applications

The electricity produced by solar cells is directly proportional to the available solar radiation and thus is inflexible. The energy produced by Solar panels does coincide with periods when the price is high.

Owners can choose to supply all solar energy generated to the grid, to use it all (or as much as possible) themselves, or to allow the feed-in to the grid to depend on specific criteria, e.g. the price of electricity. Table 2 shows the prices for a solar energy system.

Table 2: Typical APX prices when using a solar energy system

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building with solar panels	74 EUR/MWh	48 EUR/MWh
APX price 1 MWh solar electricity	89 EUR/MWh	51 EUR/MWh

With regard to the reference building, the assumption is made that the entire roof is covered with solar panels. The energy production is 65 kWh/m^2 of roof surface. The total yield of the solar system is 54,000 kWh.

Tabel 3: Energiebesparing en kostenbesparing bij het referentiegebouw

Primary energy savings	16%
Energy cost reduction (2010)	19%

Figure 17 illustrates the impact of the use of solar panels on the consumption pattern of the reference building.

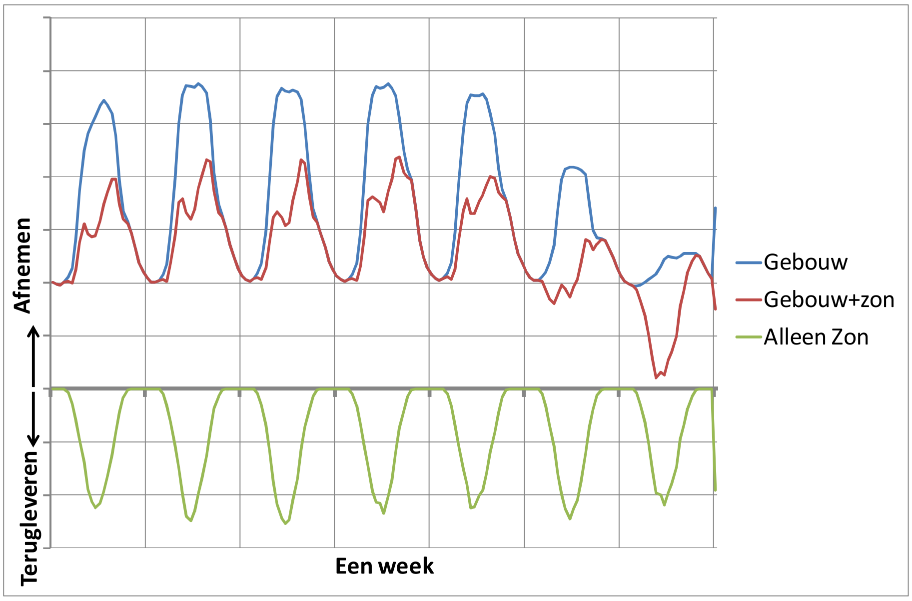

Figure 17: The impact on the consumption pattern of the reference building
[Translation: Consumption; Building; Building + sun; Sun only; Feed-in; One week]

8.2. Wind turbines

Description
Wind energy does not fit as easily into the built environment. There are small wind turbines (urban turbines) available that can be placed on building roofs for example. These turbines have a power of 0.5 to 3 kW. The yield is entirely dependent on the wind conditions. An indication is that the number of hours at full load for small wind turbines is 1000 to 2000. For the reference building this was a total maximum output of 15,000 kWh (five small turbines at 3000 kWh).

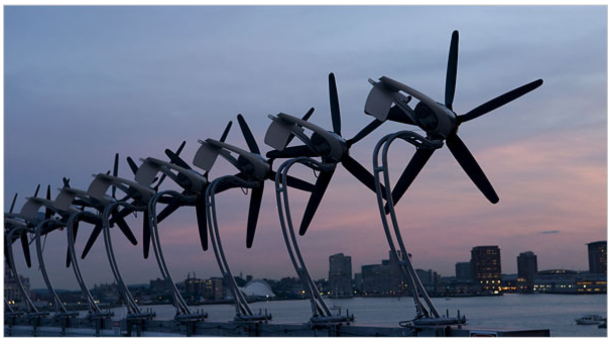

Figure 18: Small urban wind turbines (Logan International Airport in Boston)

Smart grid applications
Electricity production depends on the wind conditions. The wind conditions do not have a favourable relationship with the peak power consumption in the grid, as is the case with the sun. The electricity produced by wind turbines is inflexible.

Owners can choose to feed in all generated wind energy to the grid, to use all (or as much as possible) themselves or to allow the feed-in to the grid to depend on specific criteria (for example the price of electricity). Table 4 shows the prices relating to a wind energy system.

Table 4: Typical APX prices for a wind energy system

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building with wind turbines	78 EUR/MWh	49 EUR/MWh
APX price 1 MWh wind generated electricity	70 EUR/MWh	46 EUR/MWh

For the reference building, ten turbines were assumed with a total yield of 15,000 kWh per year.

Table 5: Energy savings and costs savings for the reference building

Primary energy saving	4%
Energy cost reduction (2010)	5%

Figure 17 shows the impact of the use of wind energy on the consumption pattern of the reference building.

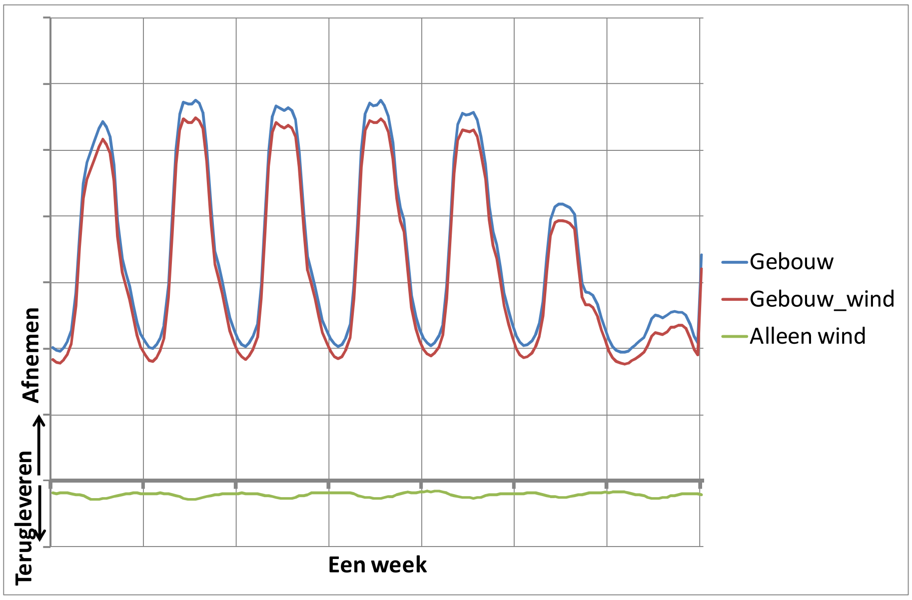

Figure 19: Impact of wind energy on the consumption pattern of the reference building

8.3. Combined heat and power

Description

Both electricity and heat are produced in combined heat and power (CHP) units. The joint production of heat and electricity provides a high return. In a built environment the requirement for heat usually takes precedence and determines the controlling of the CHP. Electricity is a by-product. CHPs can be made more sustainable by using biofuels (e.g. ethanol). There are different types of CHP systems, usually based on the combustion engine. One exception to this is fuel cells that use a chemical reaction. The smaller CHP plants are usually based on Stirling engines and the larger plants on gas engines. Gas turbines are used in power plants. Table 6 provides an overview of the types of CHP plants with their characteristics.

Table 6: Types of CHP and their characteristics

External combustion	Stirling engine	• Usually low power. • Not easy to control, usually fixed speeds, fixed power. • Used for micro-CHP.
	Organic Rankine Cycle	• Experimental. • Small to medium power. • The principle of operation is the same as the steam engine, but with a different medium with a lower evaporation temperature. • Residual heat used as energy source. • Low electrical efficiency. • Not directly controllable; some delay.
	Steam turbine	• Higher power (from about 500 kW) • Suitable for sustainable fuels because of external combustion. • Not directly controllable; some delay.
Internal combustion	Gas engine	• Medium power 15 kW-1 MW. • Suitable for specific sustainable fuels (methane and biogas) • Easy to control.
	Gas turbine	• High-power 1 MW-1000 MW. • Suitable for specific sustainable fuels (methane and biogas) • Easy to control.
Chemical reaction (fuel cells)	PE FC (PEM)	• Experimental and expensive. • Power to 250 kW (1 kW models ready for market) • Temperature level 80℃ • 30-60% electrical efficiency. • Easy to control.
	PA-FC	• Experimental and expensive. • Power to around 200 kW. • Temperature level 200℃. • 30-40% electrical efficiency. • Easy to control.
	SOFC/MCFC	• Experimental and expensive. • Power up to 1 MW. • Temperature level 650-1000℃. • 45-60% electrical efficiency.

In combination with other techniques such as absorption chillers for example, CHPs can provide an interesting energy-efficient concept. Figure 20 is a Sankey diagram of a CHP plant compared to a conventional power plant.

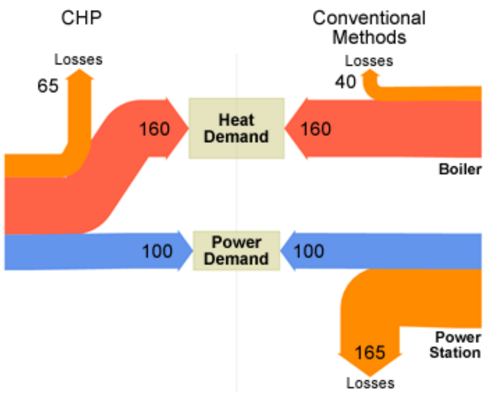

Figure 20: Sankey diagram of a combined heat and power plant compared to a conventional power plant

Smart grid application
The following is based on a combined heat and power system in the building with an electrical efficiency of 30% and a thermal efficiency of 60%. Control of the system is based on the demand for heat. In the reference building the CHP provides as much heat as the central heating system. The electricity production from the CHP can be used in the building or fed back into the grid. The flexibility of the deployment of the CHP depends on the type of CHP installed. Types that have an internal combustion engine are particularly well controllable. Under certain conditions the CHP can also supply electricity when there is no demand for heat. However there must be facilities for removing the excess heat. A heat buffer can make the use of a CHP system more flexible in a heating situation.

Table 7: Typical APX prices when using a CHP system

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building + CHP	86 EUR/MWh	50 EUR/MWh
APX price 1 MWh CHP	69 EUR/MWh	52 EUR/MWh

In the reference building the CHP system provides as much heat as the central heating system, with electricity being seen as a by-product.

Table 8: Energy savings and costs savings for the reference building

Primary energy savings	16%
Energy cost reduction (2010)	29%

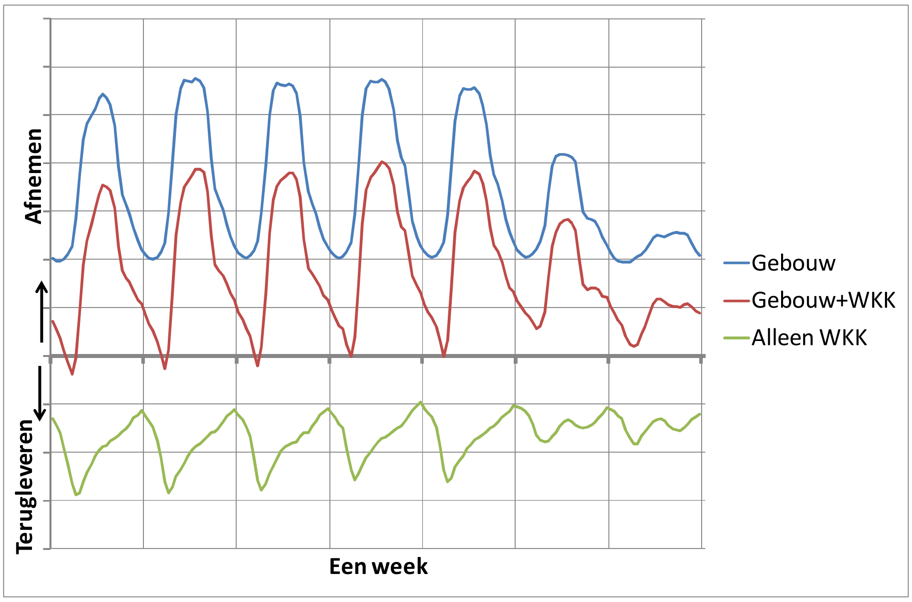

Figure 21: Impact of the CHP system on the consumption pattern in the reference building
[Translation: Consumption; Building; Building + CHP; CHP only; Feed-in; One week]

9. Peak shaving/shifting

Peak shaving or peak shifting refers to the flattening-off of peak consumption. Usually this does not result in lower energy consumption, unless a lower convenience level is acceptable. Switching on is either brought forward or delayed to avoid peak situations. This can be done because it is necessary to reduce the load on your connection, e.g. to prevent a contracted power being exceeded, or because the load on the grid has become excessive. In the latter case an external control signal is necessary. Peak shaving is usually used in building installations with a high-power, e.g. heat pumps or cooling installations. However, it is conceivable that smaller installations, such as pumps, cooling/freezing installations, electric water heaters and the like could also contribute to peak shaving. A significant degree of flexibility can be created if a lot of buildings are connected. Switching on refrigerators in 1000 houses represents about 200 kW of flexible power. Here we are focussing more on the larger switchable powered installations that may be present in a building.

9.1. Heat pumps

Description

Heat pumps can be used for both heating and cooling. Various configurations are possible. Ground heat exchangers or air-water heat pumps are usual for smaller buildings. In large buildings heat pumps are often used in combination with aquifer thermal energy storage (ATES). If ATES is used it is important that thermal equilibrium in the ground is maintained. The heat pump is at its most efficient during long periods of operation. In some cases a central heating boiler is also used for handling peak demand. The yield, expressed as coefficient of performance (COP) is between three and ten.

The installed capacity for a normal central heating system is 10-20 W/m^2 (*figures and tables from AgentschapNL*). The power required for the heat pump may be limited by insulating the building efficiently, making use of the thermal mass of the building, and using heat recovery in the ventilation air. An indication of the electric power required is 2-8 W/m^2.

Smart grid applications

In particular with modern buildings that are well insulated and have a significant thermal mass, the heat pump can be switched on and off flexibly during a restricted period. The duration of this period depends on the building. In the case of very low-energy buildings this can be as long as one day. A guide is that in the case of new buildings with sufficient thermal mass, the flexible switching can take place within a period of two hours. The use of heating power can also be limited by not cooling at night. Then no additional power is needed for heating the building.

Table 9: Typical APX prices using peak shaving with heat pumps

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building + peak shaving heat pump	68 EUR/MWh	48 EUR/MWh

The loading profile of the heat pump in the reference building was the standard consumption profile used in the energy market to trade the business consumption of natural gas. In the example the consumption between 00:00 and 12:00 is divided equally between these times.

Table 10: Energy savings and costs savings for the reference building

Primary energy savings	- %
Energy cost reduction (2010)	2 %

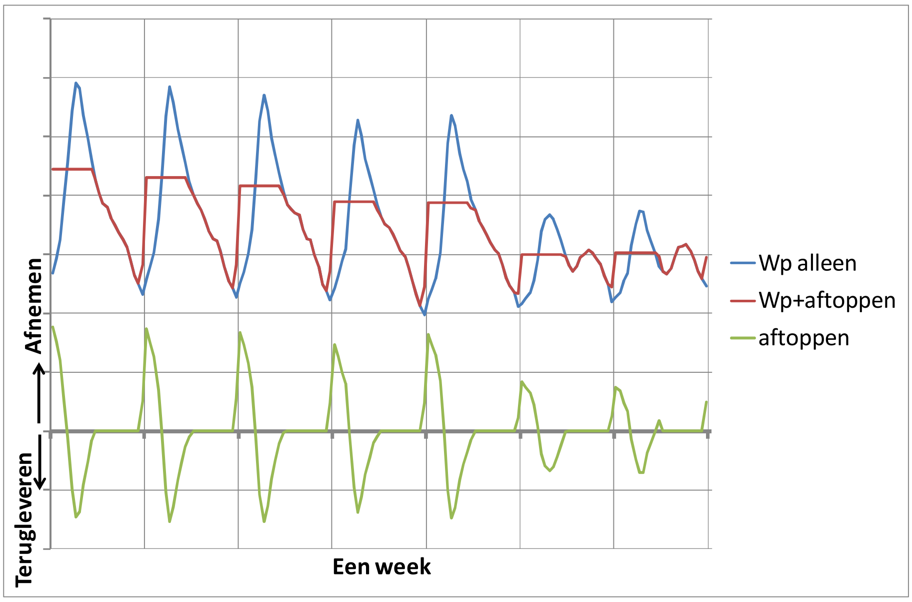

Figure 22: The impact of peak shaving on the consumption pattern of the reference building (only E consumption heat pump)
[Translation: Consumption; Heat pump only; Heat pump + peak shaving; Peak shaving; Feed-in; One week]

9.2. Cooling

Description
Cooling can also consume a great deal of power. For utility buildings a consumption of 5-15 W (electrical) per square metre can be assumed.

Smart grid application
There are several ways to make cooling installation loads more flexible, see the table below.

Table 11: Some techniques for storage of (cold) thermal energy

Storage technique	**Flexibility**
Building mass, possibly in combination with phase change materials (PCMs) that are integrated within the building mass.	A few hours
Active buffer. For example this could be an ice buffer. Or a buffer based on a different PCM.	24 hours
Ground source heat exchanger. Extracting heat from buildings by pumping up cool water from the ground in summer and returning the warmed water to the ground.	A season

In some cases an ice buffer can also be used as an emergency cooling system, e.g. for data centres.

Table 12: Typical APX prizes for peak shaving with cooling

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building + peak shaving cooling	74 EUR/MWh	47 EUR/MWh

In the reference building a cooling power of 10 W/m^2 is assumed. In this calculation it was assumed that cooling produced during the night would be stored for use during the day.

Table 13: Energy savings and costs savings for the reference building

Primary energy savings	- %
Energy cost reduction (2010)	4 %

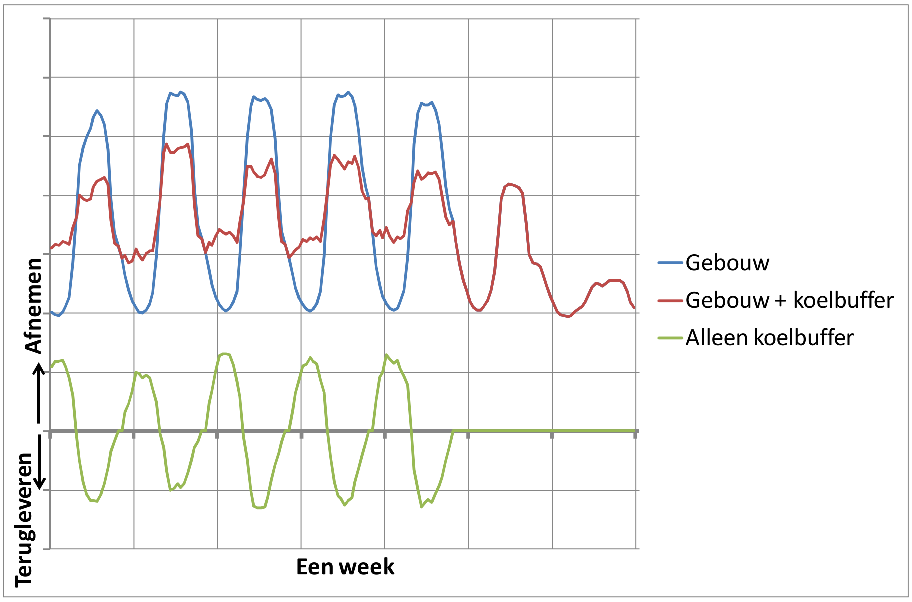

Figure 23: Impact of night buffer on cooling
[Translation: Consumption; Building; Building + cold buffer; Only cold buffer; Feed-in; One week]

9.3. Others

Heat pumps and cooling systems generally require the greatest amount of electrical power. It is also possible to control the loading within constraints for some other systems. Usually however the scope for shifting the load is rather limited. Examples are:

- Heating system pumps.
- Cooling of refrigerators or freezers.
- Laptops.
- Electric water heaters.

Because these involve smaller amounts of power, it does not really make sense to get involved with peak shaving for individual buildings. In future however it may be useful if the building is connected to a larger group such as a virtual power plant.

10. Energy storage

Eventually interruptible demand on its own will not offer sufficient flexibility to absorb temporary surpluses or shortfalls. A form of energy storage will then be necessary. Energy storage may be large-scale, e.g. water reservoirs, but it can also be local. For the time being it seems that the most suitable medium for this is the battery. This chapter discusses the various techniques that can be used for the storage of electrical energy. Of these only the battery has been elaborated with respect to the value of the buffer capacity in relation to the pricing dynamics of the APX.

10.1. Batteries

Description
Batteries store electricity in a chemical manner and can release this energy whenever required. Batteries are characterised by their capacity in kWh, their charging time and current, and discharging time and current. The efficiency of batteries is between 80 and 90%.

Smart grid application
Batteries are very flexible and can be used as buffer capacity. In the reference building example a battery was used daily to store energy in the hours that the average APX price was at its lowest and then to supply this energy in the hours when the APX price was at its highest. A charging time of five hours was used during the period 00:00-05:00 and discharging time of five hours during the period 8:00-13:00. Optimising the loading regime of a battery was not part of this study and it is likely that smarter charging strategies are possible.

Table 14: Typical APX prices when using battery

	2008	2010
APX price unweighted	70 EUR/MWh	45 EUR/MWh
APX price building	78 EUR/MWh	49 EUR/MWh
APX price building + battery	75 EUR/MWh	48 EUR/MWh
Value of storage	16.6 EUR/kWh per year	7.9 EUR/kWh per year

A battery with a 40 kWh capacity was used in the reference building example.

Table 15: Energy savings and costs savings for the reference building

Primary energy savings	- %
Energy cost reduction (2010)	3 %

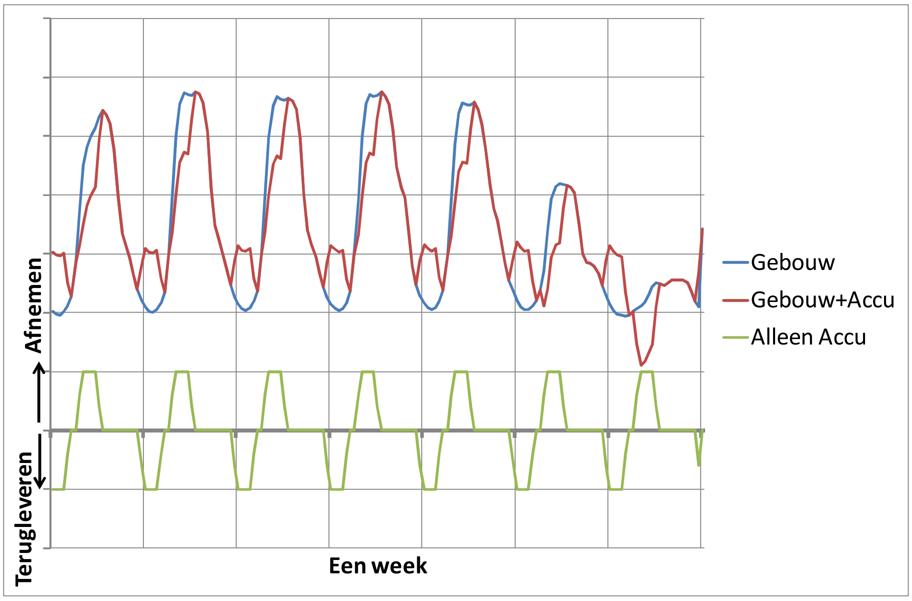

Figure 24: Impact of the battery on the consumption pattern of the building
[Translation: Consumption; Building; Building + battery; Battery only; Feed-in; One week]

10.2. Other storage techniques

Potential energy

Description
Potential energy is the energy available as a result of a height difference that is available to a mass. Water in reservoirs is usually used to store potential energy. The Lievense plan involving energy being stored in the Markermeer Lake in the Netherlands made use of potential energy. Water could also be used in the built environment, although concrete weights are an alternative. The disadvantage of these storage methods is that a lot of mass is needed to store the energy and in addition, several energy conversions are necessary resulting in low efficiency.

Calculation example
The following formula is used for the calculation of potential energy:

$$E_{pot} = m \cdot g \cdot h$$

For example consider a three story house with a concrete structure. The (concrete) weight of this house is about 250,000 kg. If this house was raised 0.5 m the stored potential energy would be equal to 250,000 kg x 9.8 m/s^2 x 10 = 1.23 MJ (0.34 kWh).

A special form of potential energy is elastic potential energy. This can be stored in a spring for example. Once again however a considerable amount of space is necessary is necessary to store a substantial amount of energy.

Smart grid application
There does not seem to be much future for potential energy in the built environment.

Flywheels

Description
A flywheel is a disc with a large mass that temporarily stores energy in the form of kinetic energy. The flywheel is particularly suitable for bridging shorter periods of time. Heavy flywheels can have a substantial response time.

Smaller flywheels, such as can be used in electric vehicles are capable of absorbing a large amount of power in a short time and can also produce a high power supply. Flywheels are less suitable for the storage of energy over a long period because of the frictional losses in the system. Advance flywheels rotate in a vacuum. Losses in the system are also caused by the conversion of electrical energy into mechanical work and vice versa.

Calculation example
The kinetic energy of a flywheel is:

$$E_k = \frac{1}{2} I \omega^2$$

Where:
I = moment of inertia of the mass around the axis of rotation [kg m^2]
ω = the angular velocity [rad/s] 1 rpm ≈ 0.104720 rad/s.

The moment of inertia for a disc can be determined by the formula:

$$I = \frac{1}{2} m r^2$$

where:
m = mass [kg]
r = radius [m]

Consider a disc with a diameter of 45 cm and a thickness of 3 cm that is revolving at 25,000 revolutions per minute. The specific gravity of the disc material is 7000 kg/m^3. How much kinetic energy is stored?

Volume of the cylinder: $\pi * 0.45^2 * 0.03$ =0.019 m^3.
Weight of the cylinder: 0.019 * 7000 (kg/m^3) = 133 kg.
25.000 rpm=3680 rad/s.

I=0.5 * 133 * 0.45^2= 13.5 kg·m^2

E=0.5 * 13.5 * 3680^2= 91 MJ.

91 MJ is equivalent to 25 kWh.

Smart grid application
Flywheels can store a lot of energy in a compact shape. In addition the reaction speed is very fast. Because of frictional losses this energy has to be used fairly quickly. This limits the opportunities for the application of the flywheel.

There are applications in the network at a higher level. Flywheels can be used to correct voltage differences as an alternative to frequency control.

Flywheel plant in New York
A 20 MW flywheel energy storage plant has been built in Stephentown in New York state. The unit can deliver 20 MW for 15 minutes. The plant generates around 10% of the reserve power for the State of New York. The plant runs about 20 cycles each day. The main advantage of the flywheel plant is its rapid response time of four seconds. Due to this rapid response the flywheel plant contributes three times more per MW power to balancing than regular backup capacity.

Compressed air

Description
Energy can be stored by compressing air. When it is compressed the temperature of the air rises and when the air expands again it cools down. The use of compressed air does result in heat losses. An adiabatic energy storage system stores the heat produced during the compression and uses this heat again for the expansion.

When compressed by a factor of 200 the pressure is increased from atmospheric (0.1 MPa) to 20 MPa. The energy stored is approximately 10 kWh/m^3 at 20 MPa.

The conversion of electricity into work to compress the air is accompanied by energy losses. There are also heat losses in the system.

Smart grid application
Small-scale energy storage by means of compressed air does not seem promising, because of the large amount of space required. Large-scale energy storage installations have been constructed that use compressed air in old salt mines.

Storage with compressed air as early as 1970
The first compressed air energy storage (CAES) plant was commissioned in the German town Huntorf in in 1978. The original capacity of the plant was 290 MW, which was increased to 321 MW during a retrofit in 2006. The plant is a combination of compressed air and gas turbine.

Hydrogen

Description
Electricity can be converted into hydrogen by the electrolysis of water. Hydrogen can then be used as a fuel for fuel cells for example. The hydrogen must be compressed after production and this is detrimental to the efficiency of the process. The efficiency of hydrogen production is approximately 50 to 80%. The energy density of hydrogen is 143 MJ/kg. Hydrogen can be converted back into electricity using fuel cells. The total efficiency of hydrogen storage is low, approximately 25% due to the various conversions.

11. Summary

This report has described the various aspects of the smart grid with the emphasis being placed on its relationship with buildings.

The main building blocks of the smart grid are local (sustainable) energy production and the ability to influence the consumption pattern (flexibility). These facilities are mainly located behind the meter. Pricing incentives will be necessary to activate these facilities. These will motivate building owners to participate in the smart grid. There are several added value aspects related to the smart grid, such as energy savings, avoiding the need to reinforce the grid and making optimum use of the price dynamics in of energy trading. The present tariff structure does form an obstacle to the user wishing to make use of these added value aspects in number of areas.

For a number of features, such as sustainable energy or peak shaving we have looked at the potential added value for a building owner based on the pricing dynamics of the APX ENDEX. In general, production facilities (solar, wind and CHP) are more valuable than facilities that only provide flexibility (e.g. batteries and peak shaving). Figure 25 illustrates the percentage savings in energy costs possible if use is made of the respective facilities in a reference building.

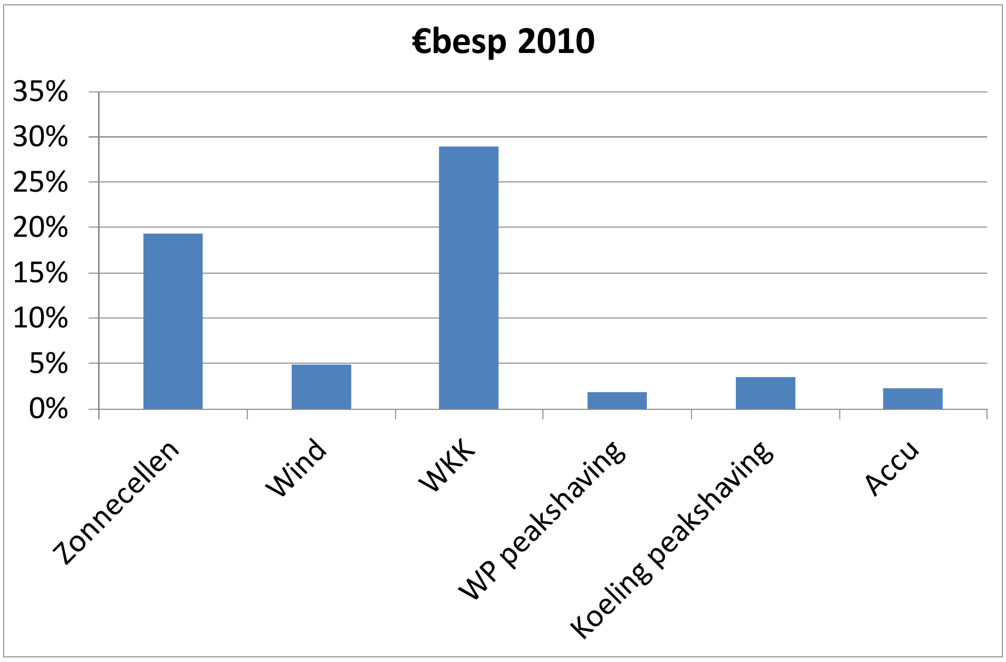

Figure 25: Energy cost savings in the reference building as a result of the various smart grid techniques
[Translation: **Savings in euros 2010**; Solar panels; Wind; CHP; Heat pump peak shaving; Cooling peak shaving; Batteries]

TVVL

Appendix 1: Overview of measures

Ideas about measures that could contribute to smart grids were collected during a number of TVVL workshops. Subsequently these measures were prioritised during a session at the TVVL technology days on 17 November 2011. The table below summarises the results of this session. It was eventually decided that this report would specifically cover energy production, buffering and interruptible demand.

	Description	Votes
1	Anticipatory building regulations.*	-
2	Solar panels.	6
3	Local exchange of excess energy.	5
4	Storage of thermal energy (heat and cold) in the ground.	5
5	Electric cars as a buffer.	5
6	Climate dashboard with feedback and control options per person.	5
7	Solar thermal collectors for heating.	4
8	Cold buffer (night tariff)	4
9	Summer night cooling.	4
10	Peak shaving (restrict simultaneous consumption of large users)	4
11	Temporary switching off cooling apparatus.	4
12	Utilisation of building physics.	4
13	Making optimum use of the flexibility of buildings by multifunctional use and efficient use of space (shut a floor in the case of low occupation)	4
14	Optimum incidence of daylight, solar tubes.	4
15	Combined heat and power.	3
16	Local synergy, complementary consumption patterns.	3
17	Using laptops as an active buffer.	3
18	Daylight control and detection of lighting.	3
19	Cloud computing, thin clients.	3
20	Benchmarking of buildings, building functions, and even people.	3
21	Thermal wheels.	3
22	LED lighting.	3
23	Wind turbines.	2
24	Bivalent (electricity/natural gas) systems.	2
25	PCMs as passive buffer.	2
26	Awareness, feedback of consumption at the level of space/person.	2

27	Organisational aspects such as increasing operating time, spreading the use time of for example kitchens or planning cleaning activities.	2
28	UPS as an active buffer.	1
29	PCMs as active buffer (cold accumulator)	1
30	Working at home and flexible workplaces.	1

* This measure was proposed as an addition to the list during the TVVL technology days.

Appendix 2: AgentschapNL reference building

For determining the impact of the various measures or features, use was made of the AgentschapNL small office reference building. A short description of this reference building follows.

The window area in the facades is approximately 35%. The building is provided with a mechanical air supply and exhaust system with a thermal wheel for recovering heat (70% efficiency). A high efficiency boiler is used for heat supply. Hot water is provided by an electric boiler. Cooling is provided by a compression chiller.

The thermal insulation of the thicker parts of the building envelope is Rc = 3.5 m^2K/W and Rc = 5.0 m^2K/W for the roof. The windows are fitted with HE++ glazing.

A high frequency lighting system (average 8 W/m^2) is installed. There is also a lighting sweep control and daylight switching with presence detection.

The starting point for the calculations was that 100% of the building was used as office space. This enables it to meet the EPC (Energy Performance Certificate) requirements.