MASTER

Distributed energy resources for a net zero energy housing development

Steenwijk case study

Morales Gonzalez, R.M.D.G.

Award date:
2011

Technische Universiteit
Eindhoven
University of Technology

Electrical Energy Systems
Department of Electrical Engineering

Den Dolech 2, 5612 AZ Eindhoven
P.O. Box 513, 5600 MB Eindhoven
The Netherlands
www.tue.nl

Author
R.M.D.G. Morales González

GraduationSupervisor
prof.ir. W.L. Kling

Coaches
prof.dr.ir. J.F.G. Cobben
ing. D. Dijkstra MBE BBA
ing. G.R. Scharrenberg MBE
B. Asare-Bediako MSc

Reference
EES.SET.11.A.238

Date
October 2011

Distributed Energy Resources for a Net Zero Energy Housing Development

Steenwijk case study

by Rosa María Morales González
Master Thesis, Sustainable Energy Technology

Where innovation starts

RENDO

Summary

The concept of zero-energy buildings (ZEB) is increasingly being perceived as a viable solution for reducing energy use in the building sector to alleviate the current worldwide energy challenges of rising prices, climate change and security of supply. By “zero net energy”, it is meant that, on a yearly basis, the building produces as much energy via renewable dispersed generation resources, as it draws from the supply grids. This graduation project is a case study for the design of a new net zero-energy neighborhood to be built in the region De Schans of the city of Steenwijk.

The design process of the system follows the concept of *Trias Energetica*. Firstly, the energy demands of the dwellings are reduced by minimizing losses and optimizing solar gains within the building envelope. Secondly, distributed renewable energy sources (RES) are implemented to meet as much of the energy demands as possible. Lastly, fossil fuels are used in the most efficient way possible to compensate for any demands that were not met by the dispersed generators (DG).

The resulting building designs were modeled and simulated in CASAnova to assess the energy performance of the building envelope and compare it to a base case in which energy is supplied solely by fossil fuels and standard building materials are used. Additionally, a low-voltage distribution network for the neighborhood was designed in Gaia, and simulations were carried out to determine whether the grid is suitable for incorporating high levels of PV modules, electric vehicles (EV) and heat pumps.

Simulation results pointed towards a final design concept that consists of a district heating CHP system fueled by a mix of natural- and green gas, as well as solar thermal water collector systems and PV modules in each house to satisfy the neighborhood’s thermal and electricity demands. In this solution, the electricity distribution grid is used as a buffer during times of low or null production, and each house is equipped with a battery storage system that enables autonomous operation for four hours.

The proposed distribution network design is suitable for a high adoption level of PV and EVs, although it is necessary to device an energy management strategy —most likely with the aid of a smart energy management control system— for load/production peak shaving during times of maximum PV production and minimum load, and the charging times of EVs during on-peak winter periods.

This solution reduces the neighborhood’s primary energy demand for heating by almost 50%. These energy savings are attributable, in great measure, to passive solar design and upgraded building materials. With these measures, the number of hours in a year in which the room temperature is comfortable without the need for space heating increased by approximately 20%, and building overheating during the summer months was reduced by approximately 7%. 33% of the total primary energy for heating comes from RES.

The combination of the PV system and the district heating CHP are more than enough to meet the household electricity demands and a 40% penetration level of EVs. Electricity-wise, De Schans can be considered a positive energy neighborhood.

At a global level, the energy balance of the neighborhood is nearly zero energy: 80% of the primary energy needs are met by renewable energy sources.

Acknowledgements

I would like to take this opportunity to thank Sjef Cobben, Gerrit Scharrenberg, Dirk Dijkstra and Ballard Asare-Bediako for their guidance in conducting my research and elaborating my report. I am also thankful to my colleagues at NV RENDO for proposing such an amazing research topic, for making me feel welcome at the company, and for sharing their practical expertise with me, especially since it cannot be learned by reading papers in scientific journals.

I would also like to express my gratitude to prof. Wil Kling for running such an amazing department in which to conduct research with a practical tinge, and for my office mates and other colleagues at EES for making all of these months of work all that more enjoyable.

This thesis is dedicated to the loving memory of my dear uncle Joe, who so tenderly cheered me on always, and believed in me no matter what. His testimony of kindness, generosity, scientific curiosity and creative genius motivate me on a daily basis to become a better person and engineer.

This report is also for my beloved sister, Angie, and my parents, Gelos and Loren, for their unconditional love and support. I keep you in my heart and my thoughts always.

To my extended family —especially my aunts, Roci and Pita—, and (PJ) friends scattered around Mexico and the U.S.: thanks for keeping tabs on me despite the ~9,000 km that kept us physically apart.

To my dear Bram, special thanks for his patience, love, and confidence; and for always letting me bounce ideas off him and lending me a helping hand.

Last, but not least, thanks are also in order to my “SET-and-friends” friends, for making life in Eindhoven and studying at the TU/e a true home away from home.

Acronyms

AC	Alternating current
ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
(μ-)CHP	(Micro-)Combined heat and power
COP	Coefficient of performance
DC	Direct current
DER	Distributed energy resources
DF	Daylight factor
DG	Distributed generators
DGS	*Deutsche Gesellschaft für Sonnenenergie*, German Solar Energy Society
DHW	Domestic hot water
DoE	United States Department of Energy
DSO	Distribution system operator
EC	European Commission
(H)EMS	(Home) Energy Management System
EPC	*Energieprestatiecertificaat,* energy performance coefficient
EU	European Union
EV	Electric vehicles
GHG	Greenhouse gases
HP	Heat pump
HRV	Heat recovery ventilation
HV	High voltage
HVAC	Heating, ventilation, and air conditioning
IEA	International Energy Agency
KNMI	*Koninklijk Nederlands Meteorologisch Instituut*
LV	Low voltage
MV	Medium voltage
NGO	Non-governmental organization
PCM	Phase-change material
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
R&D	Research and development
RES	Renewable energy sources
SHGC	Solar heat gain coefficient
SSF	Solar savings fraction
TES	Thermal energy storage
VPP	Virtual power plant
ZEB	Zero-energy building

Table of contents

DER for a net zero energy housing development: Steenwijk case study

Part I

Introduction and Literature Review

Chapter 1
Introduction

1.1 Problem Definition and Motivation for Research

Rising oil prices, anthropogenic CO_2 emissions and climate change, and concerns over the security of supply due to resource depletion and dependence on other countries have rendered the current reliance on fossil fuels for energy production, distribution and consumption economically, environmentally and socially unsustainable. A shift towards a more sustainable energy technology calls for the concept of *Trias Energetica*: reducing demand by minimizing waste, maximizing the use of renewable energy sources (RES) for the production of both heat and electricity, and utilizing fossil fuels in the most efficient, cleanest way possible [1].

Addressing these needs, the power generation sector has increasingly incorporated into its energy portfolio the use of waste heat for district heating and electricity production, as well as RES for the production of heat and electricity. However, the lower energy density and variability of RES with respect to that of fossil fuels constrains the size of the generators and requires a greater land area for large-scale implementation —an area increasingly competing with urbanization, agriculture and livestock breeding—. In addition, high transmission losses constrain the efficient transport and distribution of heat to a relatively short distribution network. This situation calls for a change in the top-down power flow from large power plants to the distribution grid via the transmission network in conventional power systems, and raises the need for integrating distributed energy resources (DER) into the electrical network. In such a power system, energy is produced by distributed generators (DG) directly connected to and dispersed along the distribution grid on either the operator- or the customer side of the meter, usually placed close to the loads. Additionally, the DG is coupled with energy storage devices and dynamic loads for active control and optimum energy management and production.

Furthermore, the EU has a commitment under the Kyoto Protocol to significantly reduce its emission of greenhouse gases (GHG) —8% with respect to 1990 levels by 2012— and has further pushed for its member States to adopt energy policies that will transform Europe into a highly energy-efficient, low carbon economy by 2030, including a 30% reduction of GHG with respect to 1990 levels by 2020 [2]. Such ambitious goals can only come by the hand of large energy savings, and with more than 40 percent of the primary energy demand of the EU being consumed in buildings, this sector has to play a major role in this endeavor [3].

In this context, the concept of zero-energy buildings (ZEB) is increasingly being perceived as a viable solution for reducing energy use in the building sector [4], [5]. By “zero net energy”, it is meant that the building delivers as much energy to the supply grids as it draws from them on a yearly basis. The proposed paths to achieve a net zero energy balance, in line with scientific literature [4]-[6], are:

- Reducing site energy demand by using low-energy building technologies and other energy efficient measures.
- Utilizing on-site DG with a high content of RES to supply the remaining energy demand.

This graduation project is a case study of a new housing complex of 400 dwellings whose aim is to have a yearly net zero energy balance, to be built in the region De Schans of the city of Steenwijk, municipality Steenwijkerland, province Overijssel, in the near future.

1.2 Research Objectives

The objectives of the project are as follows:

- Reduce the energy demand of the dwellings (lighting, appliances, heating, ventilation and cooling) with respect to the current Dutch construction code.
- Determine the electricity and heating energy requirements of the new housing complex, taking into account a very likely increase in electrical loads in the future due to a high penetration of electric vehicles (EV) and heat pumps, and a decrease in the use of natural gas networks.
- Supply the remaining energy demand by means of DER, exploring both household- and district-level solutions.
- Analyze the impact of the selected DER solution on the existing electricity distribution grid of NV RENDO to determine if traditional design is suitable to incorporate high levels of DER, and whether improvements on the grid should be made to ensure quality, stability and safety of supply.

1.3 Research Question

Based on the problem definition and the establishment of objectives, the following research question is formulated:

> *What is the best DER solution to allow the new housing complex in Steenwijk to become a zero energy neighborhood? How should the grid servicing this housing complex look like?*

In order to answer this question, the research has been broken into smaller work packages aimed at fulfilling the objectives mentioned in the previous section and answering the following sub questions:

- What type of buildings will be constructed?
- What is the goal of the municipality of Steenwijkerland regarding the EPC (*energieprestatiecertificaat*) of the new buildings? Through which technological solutions can this EPC value be achieved?
- What are the different types of potential DER solutions to cope with the energy demand?
- What should the electricity/gas/heat network(s) supplying this housing complex look like?
- Should these solutions be only grid-connected or should it be possible for the system to work autonomously from the grid for some time?
- Is the existing distribution grid from NV RENDO suitable for the incorporation of DER? How could the grid be improved?

1.4 Approach

This report is product of a 9-month investigation starting with a literature research on energy efficiency and DER concepts, and domestic energy consumption patterns in the framework of low- and zero-energy buildings (Chapter 2), as well as technological solutions for ZEB using a *Trias Energetica*-centered design approach (Chapter 3).

In Chapter 4, the case study of Steenwijk - De Schans is introduced and discussed in terms of local energy policy and the envisioned master building plan. Furthermore, the boundary conditions for the case study are set with respect to the municipality's objectives and metrics for sustainability.

Based on the findings from these sections, a concept design is elaborated and discussed in Chapter 5. The proposed (sub-)systems are simulated, and their results discussed in Chapter 6. A validation and analysis of the final concept is performed in Chapter 7, and finally conclusions and recommendations are given in Chapter 8.

A flow diagram of the design approach is sketched in Figure 1 below:

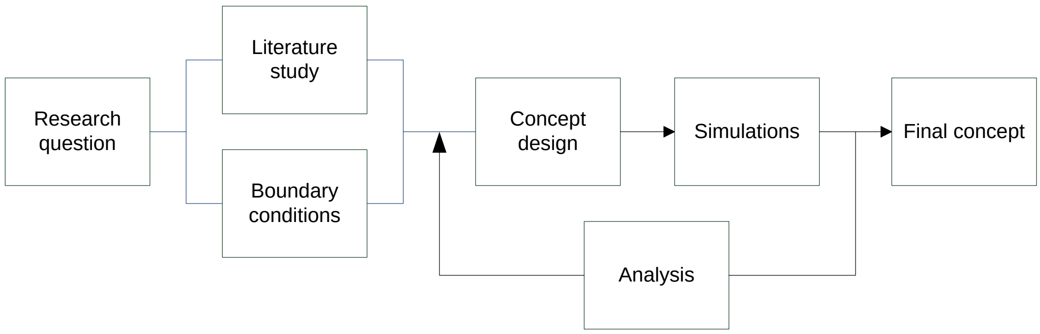


Figure 1 - Flow chart of the design approach

Chapter 2
Zero-Energy Concepts

2.1 Zero-Energy Buildings

2.1.1 Definition

The potential for energy savings within the built environment has made the term ZEB a sort of buzz word and trending topic in the realm of sustainable building. However, it could be said that the core concept of net zero-energy or energy neutrality in buildings has almost as many definitions as there are ZEB demonstration projects, depending on what the project's zero energy goal is. Torcellini, et al. [4], Marszal, et al. [5], and Hyde [6] have identified a series of boundary conditions and goals under which to group different ZEB definitions and perform the energy balances. Among these are: the type of energy use (thermal, electrical or both), primary energy use, location of the renewable energy supply (on-site or off-site), lifecycle energy use, CO_2 equivalent emissions, and energy costs. A further distinction can be made between grid-connected ZEB projects —where it is possible to balance out power drawn from non-renewable sources supplied by the electricity grid with RES-intensive DG—, and autonomous ZEB projects where the use of energy from fossil fuel sources are not allowed at all.

Based on the May 2010 recast of the EU Directive on Energy Performance of Buildings[1] [7], and the work of the authors mentioned in the previous paragraph, a definition and scope of the ZEB concept for the research project at hand is defined below:

> *A net zero-energy building is a grid-connected residential building with greatly reduced energy needs and very high energy performance, such that its thermal and electrical energy requirements can be balanced out with renewable energy sources produced on-site or nearby, using the electricity grid as a buffer.*

A synergic approach that combines technological solutions within the built environment and the electrical power system supplying the buildings is crucial for the fulfillment of this goal in terms of sustainability and occupant comfort.

[1] The Directive on Energy Performance of Buildings (2002/91/EC) is the main legislative instrument at EU level to achieve energy performance in buildings. Under this Directive, the Member States must apply minimum requirements regarding the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings [83].

2.2 Distributed Energy Resources

2.2.1 Definition

DER are small-scale[2], modular renewable power generation technologies —e.g., wind or PV farms, µ-CHP, and fuel cells— which are dispersed along an electrical network, usually placed close to the loads. Unlike traditional power systems, distribution systems and demand in DER systems are not passive; in order to achieve active control and optimum energy management and production, it is necessary to couple controllable loads and storage devices with the DG technologies.

Choosing the appropriate DG technology depends on the application and load requirements; i.e., whether DG is used as primary or standby/backup power source; whether it is intended to operate, either forcibly or optionally, in islanded mode or connected to the grid; whether the system is part of a domestic installation or operated by a utility company; and whether the DG is connected to the LV, MV, or HV networks.

2.2.2 DER in ZEB

Torcellini, et al. [4] outline a hierarchy of DER options for on- and off-site energy supply for ZEB, as depicted in Figure 2.

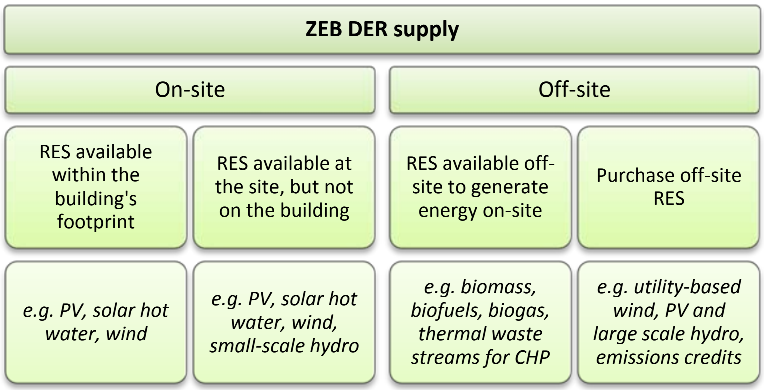


Figure 2 - Overview of possible DER supply options for ZEB (Adapted from [4] and [5])

2.3 Energy Usage and Trends to 2030

2.3.1 Heating

Average natural gas utilization per household amounted to 1609 m^3 in 2009, of which about 80% was used for space heating purposes, 18% for warm water and 2% for cooking. [8]. Using a gross calorific value of 35.17 MJ/1m^3 natural gas [9], this translates into a space-heating demand of 12524 kWh/a, or 103 kWh/(m^2a) for an average Dutch dwelling[3], which is slightly above the Dutch building code standard (*Regeling Bouwbesluit*) of 85 kWh/(m^2a) for new buildings. Taking into account only dwellings constructed after the year 2000, the average natural gas consumption for space heating was 9332 kWh/a in 2009, or 77 kWh/m²/a [8].

[2] Typically in the range of 3 to 10,000 kW [84].
[3] With approx. 121.5 m² usable floor area [38], [79]

The trend for space heating demand has shown a steady decline for the past thirty years as the building stock in the Netherlands is upgraded with better and more efficient designs, materials and equipment [10]. This is hopeful news in terms of savings, given that energy used for space heating represents roughly 60% of the total energy use in the household nowadays[4].

For instance, the *Passivhaus* low-energy building standard for space heating is 15 kWh/(m^2a) for a new construction [11]. There are around 15,000 certified passive houses worldwide, most of which are concentrated in Germany, Austria and Scandinavia. Market diffusion of this building standard, however, is still a long way from reaching maturity in the Netherlands, as there were no certified passive houses in the country up to 2008 [12].

In terms of energy policy, the Dutch government has spearheaded the Energy Transition initiative, a policy platform in which government, NGOs, knowledge institutions and businesses have been working together since 2001 in order to realize a reliable, economic and sustainable energy supply for the years to come. One of the focus themes of the Energy Transition initiative involves energy use in the built environment, and proposes a reduction of energy consumption for space heating by 30% by 2020; i.e., to drive the space heating demand down to 64 kWh/(m^2a), well below the current Dutch building code standard [13].

2.3.2 Cooling

The condition of improved building insulation brings about an increased demand for cooling energy, a market which is currently fairly untapped in the Netherlands, as only 6% of all dwellings have an air conditioning system [14]. Current cooling demand based on the dwellings equipped with air conditioning systems is estimated at 117 kWh/a, at an average operation time of 200 hours per year. According to Menkveld and Beurskens, however, “actual cooling demand is probably higher, but is not yet provided for” [14].

2.3.3 Electricity

In 2009, the average amount of electricity demand per household was 3430 kWh [15]. The 2009 revision of the report EU energy trends to 2030 describes a growing electrical energy use due to the rising demand for increased comfort in households (purchases of appliances and DHW use), and a decreased dependency on natural gas for heating and cooking purposes. The expected rates of increase for the future are 1.2% and 0.7% per annum in the periods 2010-2020 and 2020-2030, respectively, which means that the electricity demand by 2020 will approximate 3900 kWh/a per dwelling, and 4200 kWh/a by 2030 [16].

The European Commission foresees that increase rates can be contained to 1.0% and 0.4% per annum from 2010-2020 and 2020-2030, in the case that the national targets under the European Commission’s *Renewables Directive 2009/28/EC* and the *GHG Effort Sharing Decision 2009/406/EC* are achieved by 2020 in the Netherlands [16]. In such a scenario, electricity demand per dwelling will be 3800 kWh/a and 4000 kWh/a per dwelling in 2020 and 2030, respectively. Compliance with these policies can lead to annual energy savings up to 5%.

It is important to mention that these demands do not take into account the possible scenarios of increased penetration of special loads, such as electrical vehicles and heat pumps. The effect of these loads on household energy consumption will be examined in more detail in Chapter 6.

[4] Total energy use = space heating + domestic hot water (+ cooking, if gas-powered) + electricity

Chapter 3
Technological Solutions for Zero Energy Buildings

Technological solutions for ZEB follow the *Trias Energetica* approach. The first step is to minimize demand in the design stage by reducing losses within the building envelope. Then, passive solar design techniques can be implemented to maximize solar gains in winter and minimizing them in summer to reduce the contribution of the heating and electrical lighting systems without sacrificing user comfort. This way, the remaining demands can be met with renewable energy sources (e.g., active solar solutions), or by using fossil fuels in a more energy-efficient fashion.

Passive design strategies for heating aim to integrate the desired indoor conditions and the requirements of the individual building components with the process of balancing the different energy demands of the building. As depicted in Figure 3, the energy balance within the building envelope can be expressed as:

$$\begin{matrix} \textit{Transmission losses} \\ + \\ \textit{ventilation losses} \end{matrix} \quad = \quad \begin{matrix} \textit{internal gains} \\ + \\ \textit{solar gains} \\ + \\ \textit{contribution of the heating system} \end{matrix}$$

Transmission losses are the energy lost through building envelope components such as the roof, walls, floor and windows. Ventilation losses are outgoing air flows due to intentional (mechanical) ventilation or unintentional leakage through cracks and seams. Internal gains of the building are driven by occupants, appliances and other equipment inside the house, and the lighting system. The term “solar gains” refers to the passive solar contribution of energy through the glazing or thermal mass of the building. Lastly, “Internal heat production” refers to the additional energy output required to keep indoor temperature at a comfortable level for the building occupants.

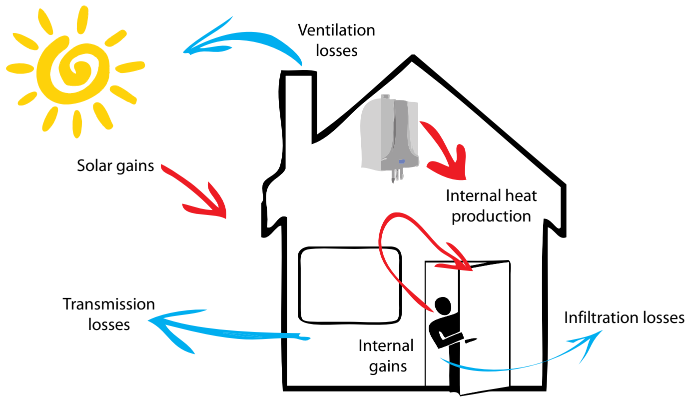


Figure 3 - Energy balance within the building envelope (Adapted from [17])

According to literature ([18]-[19]), minimization of transmission losses can be achieved through:

- Good insulation in walls, roof, floors, doors and ducts;
- Double-glazed windows with a wider air space between glazing layers, low-emissivity coatings and low-conductivity gas between glazings;
- Reducing thermal bridges in building junctions;
- Compact building shape.

Similarly, minimization of ventilation losses can be met by:

- Controlled ventilation systems;
- Reducing unwanted air leakage through more airtight weather stripping.

Internal gains due to artificial lighting can be offset by means of daylighting, whilst solar gains can be optimally made use with the proper:

- Orientation;
- Passive solar heating during winter;
- Employment of shading devices in the summer;
- Thermal mass to store the solar heat admitted each day;
- Active solar heating.

Lastly, the following technologies can lead to a more efficient use of fossil fuels:

- Heat recovery ventilation (HRV) systems with a bypass damper for summer use;
- High efficiency heating equipment;
- Low temperature heat distribution systems.

The next subsections will discuss the most important of the above-mentioned solutions in greater detail.

3.1 Passive Solutions

3.1.1 Orientation

Best industry practices dictate that the building's orientation should face due south for optimum collection of solar light and heat in constructions located in the northern hemisphere. When this is not possible on account of urban planning constraints, the general recommendation is that orientation of the building and main glazed opening be within 30° east or west of due south. The effects of deviating east or west from true south were investigated by Balcomb, et al., in 1980, and their results were reproduced in [19]. They recorded a 5% decrease in the solar savings fraction (SSF)[5] at 18° east or 30° west of true south; a 10% decrease in SSF at 28° east or 40° west of true south; and 20% decrease in SSF at 42° east or 54° west of true south.

3.1.2 Insulation

Proper insulation in the building envelope is essential to energy conservation and thus the first step in the *Trias Energetica* methodology. Grondzik, et al., go so far as to contend that the motto for solar designers should be "Insulate before you insolate" [19].

[5]The SSF is a term used to describe the solar heating performance of a building; i.e., it measures how much a solar design reduces a building's heating contribution with respect to a reference building with adiabatic walls [20].

Steve Doty echoes the same idea in his article “Energy Efficiency: Strategic Facility Guidelines” by writing, “The old saying ‘an ounce of prevention is worth a pound of cure’ is very applicable to creating energy efficient buildings” [20]. In said article, he outlines recommended insulation parameters as follows:

- Minimum wall insulation R-value 25% beyond ASHRAE 90.2 values, but not less than R-19, or U-value of 0.3 W/m²K.
- Minimum roof insulation R-value 25% beyond ASHRAE 90.2 values, but not less than R-30, or U-value of 0.19 W/m²K;
- Floor: R-30 or insulation sufficient to fill the framing cavity, R-19 minimum
- Provide thermal breaks at all structural members between outside and inside surfaces to avoid thermal short circuits (bridging).

3.1.3 Fenestration

Fenestration affects building energy use through four basic mechanisms [18]:

- Thermal heat transfer,
- Solar heat gain,
- Air leakage,
- Daylighting.

The energy effects of fenestration can be optimized by:

- Using daylight to offset lighting requirements;
- Using glazing and shading strategies to control solar heat gain to supplement heating through passive solar gain and minimize cooling requirements;
- Using glazing to minimize conductive heat loss;
- Specifying low-air-leakage fenestration products;
- Integrating fenestration into natural ventilation strategies that can reduce energy use for cooling and fresh air requirements.

A component that used to represent the greatest losses within the building envelope, windows have significantly improved their thermal performance over the past decades, going from overall heat transfer coefficients from 5.6 W/(m²K) to 0.9 W/(m²K) or less. There are even prototypes that, as of now, have recorded U-values as low as 0.3 W/(m²K) [19].

This achievement is being accomplished through multiple technological pathways, many of which have already matured into a market niche, others which are being introduced into the market, and others which are yet to be launched commercially and can only be found in pilot projects or laboratory settings. Among these, are:

- Adding a second layer of glass to the window construction (double-glazed windows);
- Increasing the air space between the glazing layers;
- Replacing the air in the gap between glazing layers with a noble gas of lower heat conductivity;
- Employing (selective) tinted, reflective, low-emissivity, photo- and electrochromatic coatings;
- More airtight weather stripping;
- Installing shading devices before, between or after the glazings (e.g., roof overhangs, intermediate films or operable blinds between glazings, venetian blinds, and curtains).

Double glazing has consolidated as the industry and building code standard for new houses over the past few years for reducing transmission losses. The U-values of this type of windows can be further reduced by applying a low-emissivity coating to one of the two glazing surfaces that face the air gap. This layer improves the heat transfer coefficient of the window assembly by blocking more radiant heat transfer between the panes than the uncoated surface. Additionally, the coating also reduces UV transmission into the living space, which reduces the fading of furniture tints and surface finishes.

For passive solar heating applications, a high-transmission low-e coating can be applied to the inner glazing for trapping outgoing infrared radiation and reducing the conduction of heat from the outer pane to the inner one. Glazing with such characteristics has a low U-factor and a high solar heat gain coefficient (SHGC or g-value). By using argon or krypton gas in lieu of air in the gap between panes, thermal conductivity can be reduced.

Industry recommendations for energy-efficient fenestration recommend a minimum overall U-factor of 1.99 W/(m²K) comprising glazing and frame, where HVAC heating is provided [20].

3.1.4 Shading

The use of shading devices is one of the most effective manners to counter solar heat gains through windows in the summertime whilst still distributing daylight into the building. These can be fitted outside the window, between the window panes or inside the living space. External devices are the most effective of the three types, as they intercept direct radiation before it actually reaches the glass [18]. These can take the shape of retractable awnings, shutters, pivoting blinds, rollers or fins, roller shades and draperies.

3.1.5 Thermal Energy Storage and Thermal Mass

Thermal energy storage (TES) is the concept of generating and storing energy in the form of heat or cold for use during peak periods [21]. It decouples the heating/cooling capacity and operating schedule of the equipment from the building load profile [22]. It also buffers the electrical load of the equipment to non-peak times, leading to a balance in demand and lower operating costs due to reduced residual ratcheted peak charges. A TES storage system avoids the need for over-dimensioning in order to satisfy peak loads, so a smaller capacity system can be installed, since production is now spread over the entire day. Without TES, a heating system would be running at a high load—i.e. high efficiency— only during peak periods, which represent only a few hours per day. A smaller heating system with less fluctuation in its operating schedule will run at higher average loads, and therefore higher equipment efficiency.

Phase-change materials (PCM) are a latent energy storage media where energy is stored and released in solid-to-liquid phase changes, and storage heat capacity is determined by a combination of sensible and latent energy. The additional latent heat reduces the storage volume by approximately 70% of that required for an equivalent-capacity sensible storage system *(see* Figure 4 *for an example)*, but increases its price per kWh by approximately 40% [21].

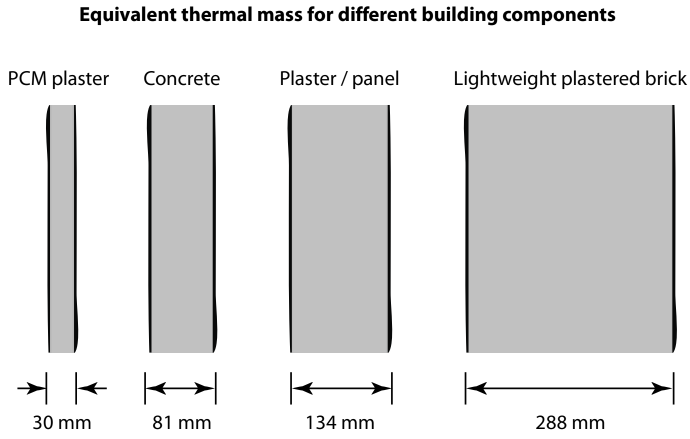


Figure 4 - Comparison of material thickness between PCM and sensible heat storage building materials with equivalent heat capacity (Adapted from [23])

The incorporation of PCMs into the building envelope is gradually becoming a more attractive alternative to simple masonry surfaces that start to lose their heat storage effectiveness at depths beyond 100mm [19]. PCMs are useful for passive solar heating applications in winter and night ventilation cooling in the summer, as they strive to keep room temperatures steady. They can be found in the form of tubes and bags of eutectic salts, or microencapsulated waxes in polymer slurries or powder form, and mixed into other building components. Such an example is the Maxit® Clima plaster, which contains 20% encapsulated paraffin-based PCM.

3.2 Active Solutions

3.2.1 Renewable Energy Sources

3.2.1.1 **Photovoltaic Systems**

Photovoltaic (PV) systems convert sunlight into electricity via semiconductors that generate electric current upon exposure to light. They can either be self-sufficient or connected to the electric grid. In stand-alone systems the solar energy yield is matched to the energy demand and generally stored in a battery. In grid connected systems, by contrast, the public electricity grid functions as the principal energy store, battery bank can also be incorporated in the system to decouple energy supply and demand in case of service outage, or for peak-load-shifting purposes.

A grid-connected PV system essentially comprises the following components:

- PV modules/array;
- PV array combiner/junction box (with protective equipment);
- Direct current (DC) cabling;
- DC main disconnect/isolator switch;
- Inverter and alternating current (AC) cabling;
- Meter cupboard with power distribution system, supply and feed meter, and electricity connection [24].

3.2.1.2 **Solar Thermal Water Collector Systems for DHW**

The market for solar thermal collectors for domestic applications has been on steady growth for the past decades in Europe [3]. Solar water heating systems can be classified by the means of fluid circulation (passive or active), the means by which heat from the collector piping system is transferred to the DHW system (direct or indirect), and the means of protection against freezing [19].

Solar thermal systems are usually comprised of [25]:

- Solar collectors/absorbers;
- short-term heat store;
- pipelines, fittings and equipment for filling, emptying and bleeding;
- solar pump (for active systems);
- heat exchanger(s);
- safety equipment (e.g., expansion vessel and safety valve);
- controller and metering devices.

An example of a widely used solar thermal system for DHW in temperate climate regions (e.g. northern Europe) is the drain-back system, depicted schematically in Figure 5. It is an active, indirect system with two internal heat exchangers: one for the solar heat feed and a second one for top-up heating by an auxiliary boiler. Its distinctive feature is that its supply- and return-flow pipes are drained whenever the solar pump is turned off (i.e., when the controller senses that no solar energy can be gathered), and the collectors will be filled with air and not water during non-operational hours. Because of this, water can be used as the heating medium without the threat of frost or evaporation in the case of extremely cold or hot climatic conditions.

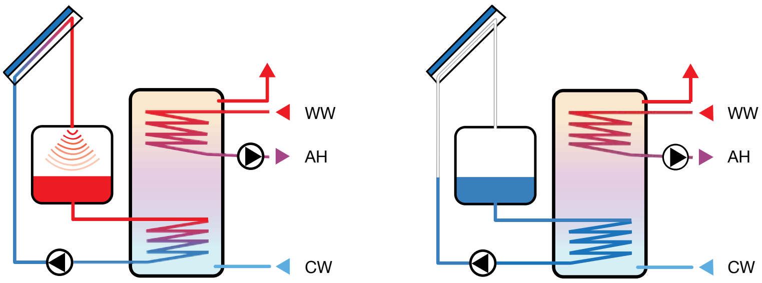


Figure 5 - Schematic of the drain-back system (Adapted from [25])

Unlike PV, where system expansions are only constrained by the availability of roof area, the components of a solar thermal system must be carefully accounted for in design phase, as piping, the solar pump, storage tank and heat exchangers are sized for a specific collector output.

Design guidelines in literature ([3], [19], [25]) propose the following considerations for solar thermal DHW systems based on a consumption rate of 30-60 l per person per day and a collector yield of 350-450 kWh/(m²a):

Table 1 - Sizing guidelines for solar thermal DHW systems (adaped from [3])

Component	Dimensions
Collector	
Flat plate	1.1-2.3 m² per person
Vacuum tube	1.00-1.20 m² per person
Storage tank (pressurized)	40-70 l per m² collector surface area
Heat exchanger	30-40 W/K power per m² collector surface area
Hydraulics	Piping: 15 mm external diameter 50 m maximum pipe length Pumping power: 25-80W

Such a system is expected to cover approximately 40-60% of the annual DHW demands; 70-100% in the summer and 10-20% in the winter.

3.2.1.3 **Cogeneration**

Cogeneration, also known as combined heat and power (CHP) production, is the process by which useful heat and electricity are simultaneously generated from a single fuel or energy source. Because thermal energy can only be transported over relatively short distances, the heat and electricity produced are intended for use at or near the site of production. Pehnt, et al. define µ-cogeneration as systems of up to 15 kW_{el} that can be directly connected to the LV grid, and whose use is intended for single-family homes, apartment houses, and small business or hotels [26]. This definition then helps differentiate µCHP units from larger, yet still small-scale systems (up to 50 kW_{el}) for neighborhoods or districts that require an additional heat distribution system.

CHP with district heating can achieve similar CO_2 reductions as µ-cogeneration, and have a similar economic performance. In urban areas with high heat density or neighborhood clusters, district heating with cogeneration is a more attractive technological solution, whereas micro-cogeneration may be particularly interesting in areas with more dispersed buildings. The main reasons for this are:

- A high number of connections are easy to achieve in development areas where new buildings are being constructed.
- The combination of RES with fossil-fuel-based CHP systems is much easier, especially when certain minimum size for a supply technology (e.g. biomass) is required.
- Where local biomass resources are available, larger-scale, central CHP plants with district heating systems are technologically better suited than µ-cogeneration to make use of their potential.

3.2.1.4 **Heat Pumps**

Heat pumps enable the useful application of energy available in large heat sinks to be applied in the built environment. They transfer this energy in a closed thermodynamic cycle from ambient temperature to a temperature level that is required for heating or cooling applications [27]. There are several heat pump technologies suitable for built environment applications; some are already mature, whilst others are still in R&D stage, or are available only at a small scale.

Compression heat pumps are the most widely used in heating and cooling applications nowadays. They consist of two heat exchangers —a compressor and an evaporator—, a reversing valve, two metering devices and two bypass valves that allow for the unit to provide heat and cooling. They have a very good coefficient of performance (COP) in comparison with other technologies, and can work in low temperature heating conditions. The heat source/sink used for the heat exchange can be air, water or the ground.

A ground-source heat pump, for example, uses a water loop in the ground (or a geothermal aquifer, in open-loop systems), as the heat source/sink for the operation of the compression heat pump. Because ground temperature is more stable throughout the year than ambient air, they have higher efficiencies than air-source heat pumps, and are less vulnerable to frost during cold winters.

Some advantages of ground-source heat pumps are [28]:

- In a new construction, the technology is relatively easy and cost-effective to incorporate.
- It is possible to implement them for applications where multiple heating zones or individual load control are needed, because they are primarily designed using multiple unitary systems.
- They are considerably more efficient than other electric heating systems, as they operate with a COP of 3.0-4.5.

In spite of their relatively high efficiencies, their operation still demands very high electrical inputs (1.8-50 kW, depending on the application), and can potentially become a burden for the electricity grid in the case of high penetration levels and high simultaneity of the loads.

3.3 Energy Efficiency

3.3.1 Ventilation Strategies

Balanced ventilation systems with passive heat recovery (HRV) consisting of air-to-air heat exchangers or heat recovery ventilators are appropriate energy-efficient solutions for new houses with tightly constructed envelopes [18]. In such a system, fan-induced supply and exhaust air flows at nearly equal rates over a heat exchanger, where heat is transferred from the outgoing to the incoming airstream in the cross-flow *(See* Figure 6*(i))*. As the fresh supply air has now been preheated, energy required to condition ventilation air is reduced, and the thermal discomfort that occurs when untempered air is introduced directly into the house is minimized. For the summer months, the heat exchanger needs to be bypassed with a damper to avoid overheating of the living space *(See* Figure 6*(ii))*.

With any HVAC system, meticulous design, installation, operation and maintenance of mechanical ventilation systems need to be carried out in order to ensure occupant comfort, energy efficiency, service life and indoor environmental quality. With this system in particular, it is also of utmost importance that the system operates in a balanced state: outgoing and ingoing airflows need to be the same. An unbalanced system not only leads to poor airflow (and thus, air quality) and poor heat recovery (and thus, poor energy efficiency), but it may also change the pressure of the living space relative to the outside, particularly in tightly constructed homes. In cold climates, for example, pressurization of the living space can cause condensation in building cavities that can deteriorate the building materials and lead to structural damage. Depressurization may cause back-drafting of combustion appliances (e.g., furnace, water heater or fireplace) and infiltration of contaminants (e.g. car exhaust gases or insulation particles) into the living space, rather than leaving the house via the chimney [29].

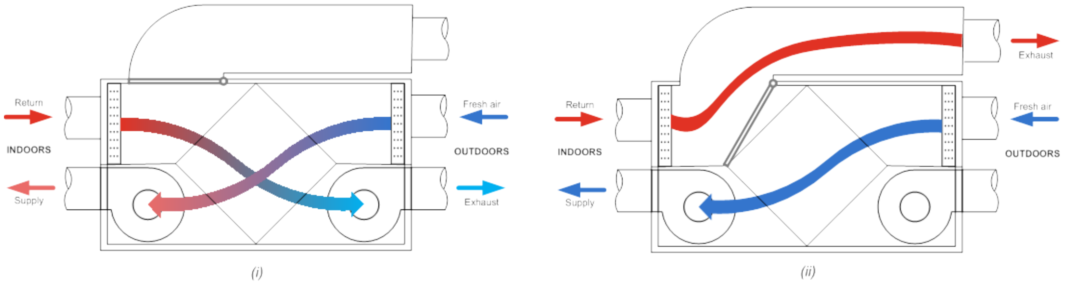


Figure 6 - Balanced HRV system operation in (i) winter (ii) summer

3.3.2 Terminal Systems

Terminal systems are responsible for delivering energy from the heating system to the room. Nowadays, high-temperature (70/55°C) radiator distribution systems are the norm, but with technological advances in the fields of heat exchangers and thermal heat storage, more energy-efficient terminal systems working at lower temperature ranges have become more readily available [30].

An example of such a system is underfloor heating, where water flows through coils installed under the floor covering and above a layer of rigid insulation to ensure that energy is mainly transferred to the surface of the floor, which will in turn transfer it to the surroundings via radiation and convection. The combination of the insulation and floor covering make for a relatively small thermal mass and fast response time. This is, in principle, easy to control and regulate, although the heat output will ultimately depend on the thermal resistance of the floor and the furniture placed on it. Since the system covers the entire floor area, only a low temperature difference (35/28°C) is needed to deliver the necessary energy to the room, thus enabling a wider variety of heat exchangers working at higher efficiencies, other than the traditional high-efficiency gas boiler (e.g. heat pumps, µCHP).

3.3.3 Smart power management systems

Home energy management systems (HEMS) are control devices that monitor and manage lighting, temperature and appliance control at household level, typically through a computer-aided user interface. They feature programmable, automated routines for the turning on and off of the lighting system and the opening/closing action of shades and curtains to reduce the demands of the climate control system, as well as programmable thermostats with adaptive climate control. Other capabilities include: real-time energy consumption and pricing monitoring, demand response event notification, and load shifting of electrical appliances within the home area network, such as the dishwasher, refrigerator, tumble dryer, and washing machine [31].

Other devices can manage loads and route energy produced from renewable resources for direct consumption, storage, or trading with the utility company, such as the PowerRouter, developed by Nedap NV. According to the product's website, the PowerRouter performs not only as a conventional HEM system, but takes over the functions of inverters, monitoring devices, switchboxes and inverter-charger combinations in a DER system [32]. Units of up to 5 kW are able to connect and manage DG sources, loads and storage. They have uninterrupted power supply (UPS) functionality, an integrated charge controller for battery storage, a DC switch for DC loads, and Web capabilities for remote monitoring and control. Labeled as suitable for on-grid, off-grid and smart-grid solutions, it is possible to interconnect multiple PowerRouters for greater capacities. Although this device has great potential for management of micro- and mini-DER networks —i.e., administering DG and loads for a single household, or acting as a virtual power plant (VPP) manager for a small DG-network serving a cluster of houses or apartments—, its price is yet to be competitive with commercial inverters for PV applications.

Chapter 4
Steenwijk - De Schans

4.1 Towards a More Sustainable Steenwijkerland

In 2009, the municipality of Steenwijkerland traced a three-year roadmap in which the framework for the role of sustainability in urban planning and development for new and existing buildings was laid out [33]. Among the most important and ambitious goals of Steenwijkerland's Sustainability Plan 2009-2012 is to save energy in the built environment in order to positively impact housing costs and CO_2 reductions. This will be achieved by favoring the construction of energy efficient —preferably energy neutral and/or passive— buildings via pilot programs, subsidies, and strategic partnerships with the energy network administrator, housing corporations, architects, contractors and the surrounding municipalities to form the workgroup "*Duurzaam Bouwen*". [34].

One of these pilot projects is Steenwijk-De Schans. Since the year 2000, the municipality has had a keen interest in developing the fields in the southern quarter of Steenwijk into a residential area. After negotiations with the State Council regarding the zoning plan reached a stalemate, the municipality decided that a fresh start and a novel approach on the design were necessary [35].

4.2 De Schans, "A Landscape in Which to Live"

In line with its sustainability goals, the municipality has decided to involve many different stakeholders in the design process —e.g. the local residents, potential buyers, parcel owners, interest groups, and the regional water authorities— to make De Schans a sustainable area for collective living whilst preserving the cultural-historical quality of the landscape [36], [35].

The plan was drawn up by the municipality in collaboration with the firm Onix Architecten and the consultancy firm BVR. The municipality will offer lots, and the houses will be built by the development firms. After the master building project was approved in 2009, the municipality initiated a legal process in 2010 to secure the necessary permits for construction. This year (2011), urban and quality planning will be presented to the mayor and executive board to begin zoning and construction in the near future (2013, according to [37]).

The master building plan of De Schans calls for 400 residences consisting of detached, semi-detached and terraced houses, as well as collective housing (i.e. apartments) for starter and retirement homes and collective private commissioning as pictured in Figure 7. Despite the several starts and stops of this project, from the available sources of information, it appears that the master plan submitted to the mayor and executive board for approval this year is the same as the one pictured in this report [35].

Figure 7 - Master plan for Steenwijk - De Schans [35]

The breakdown per type of house is assumed to correspond to the layout of the master plan. These figures, which will be used to further the case study in the upcoming chapters, are shown graphically in Figure 8.

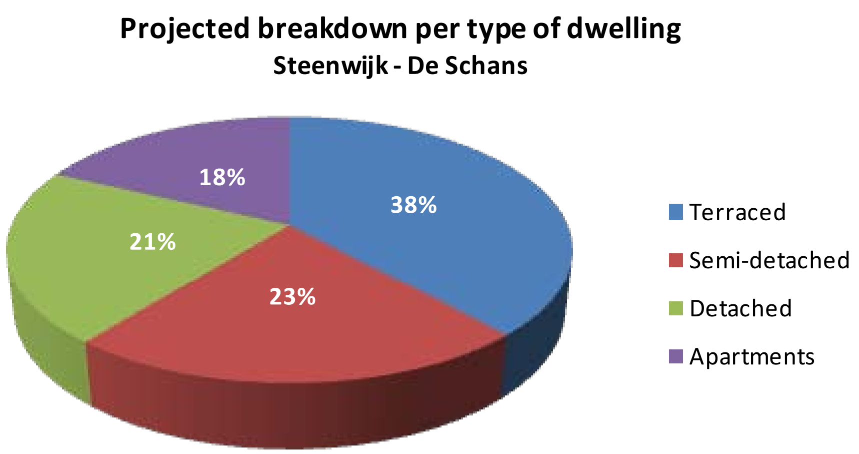


Figure 8 - Share of each housing type in the Steenwijk - De Schans project

4.3 Steenwijkerland's Sustainability Objectives

The municipality expresses its choice, although not explicitly, of the principle of *Trias Energetica*, as the way to reach the energy neutrality and/or energy efficiency ideals on the road to 2030 [33]. Steenwijkerland is well aware of the energy saving potential within buildings. It is their plan to reduce energy demands in the building envelope via better insulation materials and passive solar design, in order to then supply the remaining demand with renewable energy technologies. For heating applications, they advocate:

- Thermo-solar systems,
- Geothermal energy storage via open-loop aquifers for use in combination with heat pumps;
- Biogas for feeding high-efficiency boilers and/or (micro-)cogeneration units;
- Low temperature heat exchangers and heat recovery terminal systems.

Of particular interest to both the municipality and the Renewable Energies branch of NV RENDO, RENDO Duurzaam, is biogas. The company has outlined a strategic plan to incorporate upgraded biogas (green gas) into its natural gas networks in a share of 20% by 2030 [38]. In the framework of this plan, in the region of Steenwijkerland, feasibility studies are currently being made to start up a biogas digester in the village of Giethoorn. Delivering the biogas to a CHP plant with a district heating system that could eventually supply the new neighborhood of De Schans is thus an extremely attractive possibility, especially in terms of the technological advantages of concentrating the biomass resources in a central power plant, as discussed in the previous chapter.

For electricity applications, they mostly encourage the use of PV systems. Although the municipality has a keen interest in wind energy, they have encountered problems in reaching a consensus with the citizenry and utilities regarding a suitable location for the turbines [33], and have thus relegated wind energy to a secondary place in their priority list.

4.3.1 Metrics of Sustainability

In an attempt to come up with a reasonable metric for their sustainability goals and quantify the extent of energy efficiency measures in the new constructions, the municipality set, as a design guideline, the reduction of the energy performance coefficient (EPC) from 0.8 (the Dutch building code standard until 1 January 2011) to 0.4 [33].

However, the EPC per se is not meant as a tool for calculating actual energy use and thus makes a poor design parameter. It is a metric of the building-related energy consumption under standard conditions —i.e., properties of the building envelope materials and energy efficiencies of the heating and lighting systems—, and does not take into account the consumption patterns of its inhabitants [39].

The problems of having the EPC as a benchmark for sustainability were experienced by the municipality in 2010 [34]. Theoretically, better insulation should always lead to a lower EPC, given the heating requirements of the house decrease. However, when used in combination with heat pumps, the lower heating requirements cause the heat pump to deliver a lower output in detriment to the system efficiency, causing the EPC to shoot upward. In contrast, using a heat pump in a house with larger heating requirements (i.e., less insulated) demands a larger heat output and therefore a higher conversion efficiency, which lowers the dwelling's EPC, in spite of the fact that it is using far more energy than a well-insulated house.

Because of these reasons, the EPC will not be used either in the design methodology or as a metric of building performance. Sustainability will be measured in terms of energy savings, keeping in line with the principle of *Trias Energetica.*

Part II

Design Proposal and Analysis

Chapter 5
Design Proposal

5.1 Energy Demands

5.1.1 Heating

The De Schans development will consist of 400 dwellings in total, of which 153 are terraced, 90 are semi-detached, 85 are detached, and 72 are apartments, as discussed in the previous chapter. The heating demands of each different type of household are based on the *Referentiewoningen Nieuwbouw* report prepared by SenterNovem for the VROM Ministry in 2006 [40], in which the most common types of dwellings being built in the Netherlands are characterized in terms of geometry, heat transfer coefficients of the building components, and installation details (e.g., heat transfer (i.e., terminal) systems, heat exchanger (boiler) and ventilation).

The basic characteristics of each of the reference dwellings are discussed in Appendices A.1-A.4, and their typical energy use for space heating and DHW[6] is summarized in Table 2 below:

Table 2 - Heating demands per type of household

	Energy demands [kWh/(m²a)]		
Type of dwelling	**Space heating**	**DHW**	**Total**
Terraced	76.4	23.3	99.7
Semi-detached	88.1	23.3	111.4
Detached	92.5	23.3	115.8
Apartment	73.5	23.3	96.8

As discussed in the literature review in Part I, the implementation of passive solutions in the building envelope during the design phase enables the curtailment of the energy demands for space heating without sacrificing user comfort. The passive design strategies from Section 3.1 will be sized for the De Schans case in the following paragraphs, and the extent of these measures will be attempted to be quantified through simulations in Chapter 6, based on the model of the reference buildings described in Appendix B. The benchmark for energy savings will be set at 30% less with respect to the 2009 values(72 kWh/(m²a) or 54 kWh/(m²a) for new buildings), in accordance with the Dutch Energy Transition goal.

[6] Recalling section 2.3.1, annual DHW demand for an average Dutch household amounted to 2833 kWh in 2009. The same figure will be used for 2030, as DHW consumption patterns have been more or less stable over the years, and are not expected to change in near future [63]. Since DHW consumption is occupant-driven, DHW demands per m² floor area were calculated using the average Dutch household size, thus yielding the figure of 23.3 kWh/(m²a).

5.1.2 Electricity

Electricity demands for each type of household were calculated based on the analysis of 2009 load data from a MV/LV substation operated by NV RENDO in the nearby city of Hoogeveen. With the aid of a map of the distribution station, reproduced with permission of NV RENDO in Figure 9 below, it can be seen that the substation serves 178 terraced houses, 50 apartments and 46 semi-detached houses, for a total of 274 dwellings. It is assumed that similar load behavior can be expected of the future distribution network of the De Schans project due to the purely residential nature of the customers that this particular substation serves.

Figure 9 - Calkoenstraat LV distribution network, Hoogeveen (Image courtesy of NV RENDO)

The yearly demand at the substation amounted to 996 MWh, or an average of 3635 kWh per household per year. This figure is slightly higher than the 2009 national average of 3430 kWh/a referenced in Section 2.3.1. Based on the demands for 2009, the total number and types of dwellings in the distribution network, and figures for floor area per type of dwelling from Appendix A, the electricity demand per floor area was found to be approximately 30 kWh/m²/a. Taking this figure into account, the following demands per type of dwelling were calculated:

Table 3 - 2009 electricity demands per type of household

Type of dwelling	Demand [kWh/a]
Detached house	5116
Semi-detached house	4458
Terraced house	3751
Apartment	2466

Projected demands for 2020 and 2030 are based on the scenario In that case, the future electricity demands per average household would be 4132 kWh/a in 2020 and 4431 kWh/a in 2030. Table 4 shows the expected electricity demands in 2020 and 2030 per type of household:

Table 4 - Future electricity demands per type of household

	Yearly Demand [kWh/a]	
Type of dwelling	**2020**	**2030**
Detached house	5816	6236
Semi-detached house	5068	5434
Terraced house	4264	4572
Apartment	2803	3006

If the European Commission policy goals regarding renewables and GHG emissions are met in the Netherlands by 2020, the expected average electricity demand per household would be 4051 kWh/a in 2020 and 4216 kWh/a in 2030. The breakdown per type of dwelling for this scenario is shown in Table 5:

Table 5 - Future electricity demands per type of household, 2020 EC targets regarding RES and GHG met

	Demand [kWh/a]	
Type of dwelling	**2020**	**2030**
Detached house	5702	5934
Semi-detached house	4969	5171
Terraced house	4181	4351
Apartment	2749	2860

Assuming the EC goals are indeed met, the total energy demand for De Schans is calculated at 1770 MWh/a in 2020 and 1840 MWh/a in 2030. The energy savings with respect with the scenario depicted in Table 4 amount to almost 1MWh/a.

5.2 Passive Design

5.2.1 Passive Solar Building Parameters

Appendix F of the Mechanical and Electrical Equipment for Buildings handbook consists of guidelines and information for heating (and cooling) design of passive solar buildings [19]. The handbook outlines criteria for sizing south-facing glazing areas for passive solar design based on the climatic characteristics of U.S. and Canadian cities. In order to adapt these guidelines to the Steenwijk case, the Köppen-Geiger climate classification system and the work of Peel, et al. [41], were used in order to locate the U.S. or Canadian city with the most similar climate to that of the Netherlands.

Figure 10 below depicts the Köppen-Geiger climate regions of Europe and the Middle East. It can be seen that the climate of the Netherlands is classified as *Cfb*, temperate without a dry season in the year and warm summers [41].

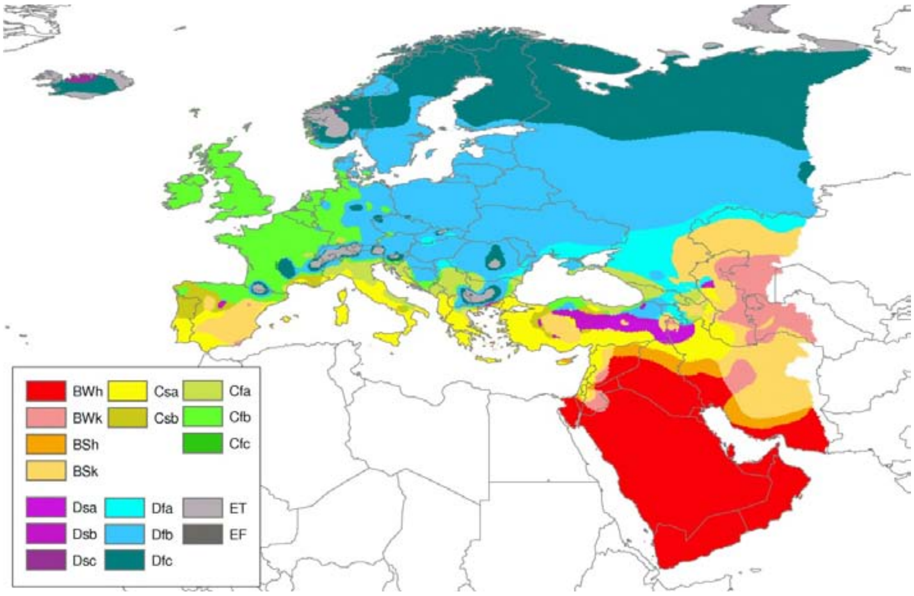


Figure 10 - Köppen-Geiger climate type map of Europe and the Middle East [41]

Homologous climatic conditions can be found in the North American continent around the Vancouver area of British Columbia, as shown in Figure 11. Passive solar building parameters from this city will be used for calculations and design considerations in the Steenwijk De Schans project.

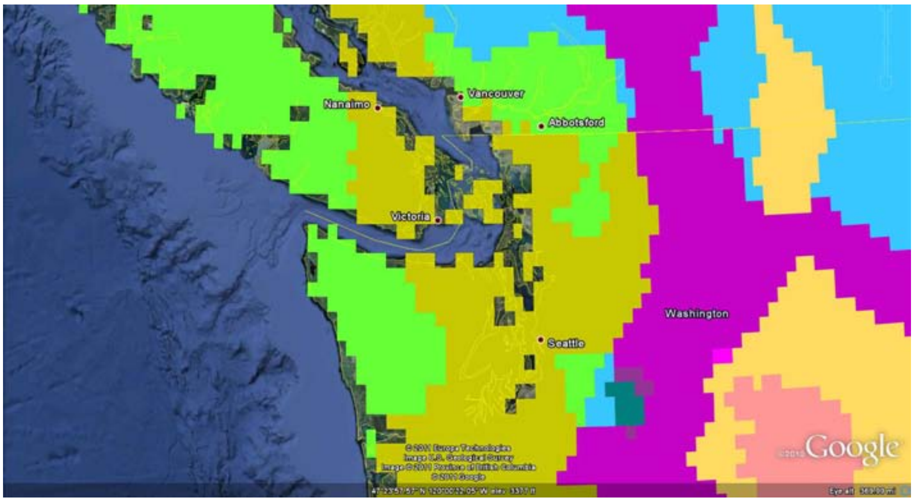


Figure 11 - Köppen-Geiger climate type map of the Vancouver area, Google Maps overlay (Adapted from [41])

The ratio between the south-glazing area and floor space should range from 0.13 to 0.26 in order to achieve optimum solar gains. The expected SSF from these measures lies between 40 and 60% [19].

5.2.2 Thermal Mass and TES

With the expected SSF of the building, it is possible to calculate how much thermal mass is needed to store the solar heat admitted daily. Table F.2 of [19] outlines the recommended effective thermal storage area of water or masonry per unit of solar collection area for direct and indirect gain systems as a function of SSF. "Effective area" refers to the area exposed at some point to direct sun during a clear winter day. The table also gives the recommended thermal storage by weight of water or masonry per collector area for the same SSF value. In the case of expected SSF for Vancouver, the effective thermal storage area per unit collector area should range from 2.9 to 4.4 for a 100-mm thick brick wall with a density of 1970 kg/m³ and a specific heat capacity of 0.79 kJ/(kgK). The thermal storage weight should be between 586-879 kg of masonry per square meter of glazing area. This translates into a thermal mass requirement per wall area of 157.8-159.6 kJ/(m²K) [19].

Adding a 15 mm-thick layer of Maxit® Clima PCM plaster to the masonry, for example, increases the thermal mass per wall area by roughly 20 kJ/(m²K), which means that the needed ratio of effective thermal storage area per unit collector area would decrease by approximately 10 percent[7].

5.3 Active Design: DER for electricity and heating

5.3.1 PV Generation

The calculations for the specific yields and capacity requirements of the PV system for the neighborhood were based on the meteorological data from KNMI [42] and design guidelines from the German Solar Energy Society [24], and can be found in Appendix C.

A total installed capacity of 2.0 MWp is required to satisfy the electricity demand of De Schans by 2030. Each household will have a PV system installed in the roof, and the LV grid will act as a buffer to compensate for the mismatch between the energy supply and demand. Without having the need for storage, it will be possible to draw electricity from the grid during periods of null to low production, whilst any excess production during the daytime can be fed into the grid.

Commercially available modules and inverters that were suitable for this application were looked up in the catalogues of the Polysun 5.6 Simulation Software [43]. Polycrystalline-Si HS-PXL-220 solar panels manufactured by Heckert-BXT Solar GmbH were selected. Each module has a nominal power of 220W and an efficiency of 15%. For the purpose of simplification, a single inverter model was selected for all four applications. The Sunny Boy 7000-US-240 is a one-phase inverter manufactured by SMA Solar technology AG, and has 7 kW nominal capacity and efficiencies of 94-97% depending on the fraction of nominal power at which it is operated.

The number of modules and surface areas required for the above installed capacity requirements are shown in Table 6. The modules for the apartments are connected to the inverter in a single string, whilst the modules for the terraced, semi-detached and detached houses are arranged into two strings to keep the input voltages and currents of the inverter within its operational ranges.

[7] The physical properties of the Maxit® Clima PCM plaster are as follows: density: 1340 kg/m³; specific heat capacity outside the melting range: 1 kJ/(kgK); melting temperature range: 23-26°C; latent heat of fusion: 18 kJ/kg [82].

Table 6 - Commercial PV modules - requirements per type of house

Type of house	Number of modules	Installed capacity [KWp]	Area required [m²]	Available roof area[8] [m²]
Terraced	22	4.8	32.2	40.9
Semi-detached	26	5.7	38.1	46.4
Detached	30	6.6	44.0	50.4
Apartment	15	3.3	22.0	30.0

As it can be seen from the table above, the available roof areas in all four housing types are sufficient to mount the PV modules. With these figures, the total installed capacity will total 2.05 MWp for an expected yearly energy production of 1891 MWh.

The combined PV output profiles for the whole neighborhood during a typical winter and summer day are shown in Figure 12:

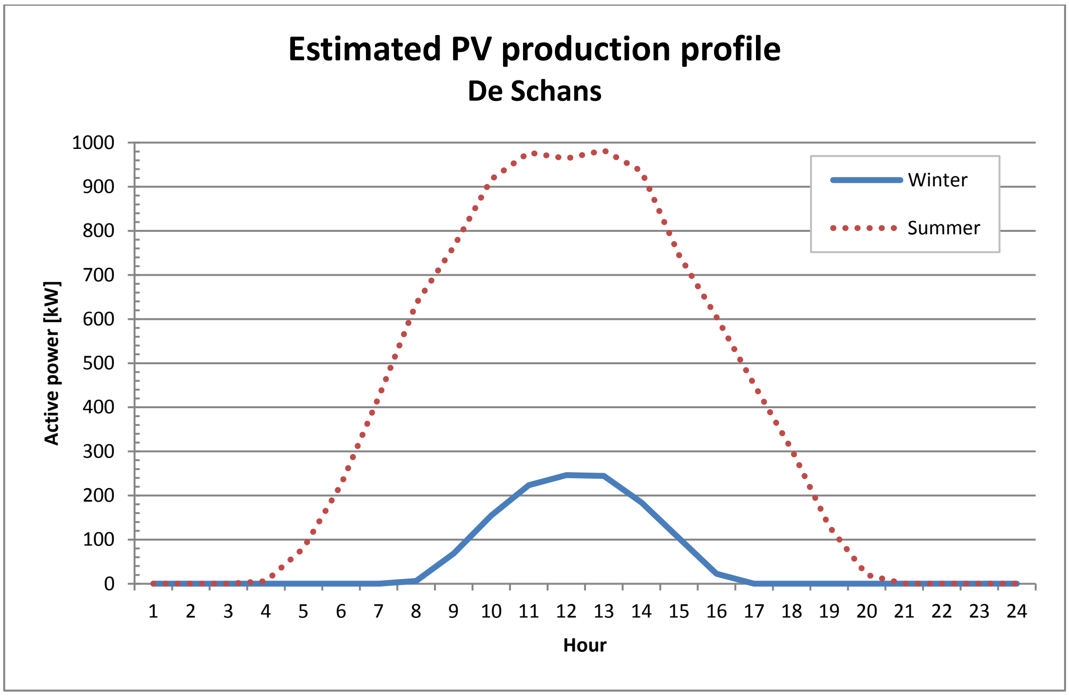


Figure 12 - De Schans PV output profile for a typical winter and summer day

5.3.2 Solar thermal DHW system

A drain-back solar thermal DHW system is selected for this application. The collectors are glazed flat-plate absorbers with a spectrally-selective black chrome coating[9], which are cheaper than vacuum collectors, yet still yield a very good price/performance ratio when compared with unglazed, uncoated flat-plate collectors. The average annual efficiency of a complete system with glazed flat-plate collectors is 35-40% [25].

DHW demands per household, as seen in Section 5.1, are 2833 kWh per year, or 7.7 kWh per day. The desired solar contribution to the DHW system is 100% in the summer months. The average daily insolation in summer, taken from tabulated values in Appendix C, is 6.1 kWh/m².

[8] The available roof areas were based on the building models in Appendix B. In the case of the detached house, the roof needs to be oriented east-west rather than north-south. In the case of the flats, it is assumed that the PV modules will be installed at the optimum tilt angle (52°), and that the building's roof area is divided equally among the number of apartments in the building (e.g., 4 floors, 1 apartment per floor).

[9] Absorption rate, α, between 90-95% and emissivity rate, e, of 5-15%.

The required collector area for this system is given by the following equation, as per design guidelines from [19]:

$$\text{collector area} = \frac{\text{daily heat need } [kWh/d] \times \text{solar contribution } [\%]}{\text{daily insolation } [kWh/(m^2 d)] \times \text{system efficiency } [\%]} \tag{1}$$

For the case at hand:

$$\text{collector area} = \frac{(7.7kWh/d)(100\%)}{(6.1kWh/(m^2d))(35\%)} = 3.6m^2 \tag{2}$$

Commercial collector systems with 3.6 m² absorber areas will take up approximately 4.0m² roof space [43]. The roof areas of all four types of dwellings in the case study are enough to house both the PV and solar thermal systems.

The short-term heat store needed for this application is a 300-liter tank, and was sized using the rule of thumb from Section 3.2.1.2 (60 liters per m² collector area and rounded up to a commercial-size tank).

The expected solar contribution to the DHW system per month is depicted in Figure 13. The annual energy yield of the system is estimated at 437 kWh/m², or roughly 56% of the yearly DHW demand of each household.

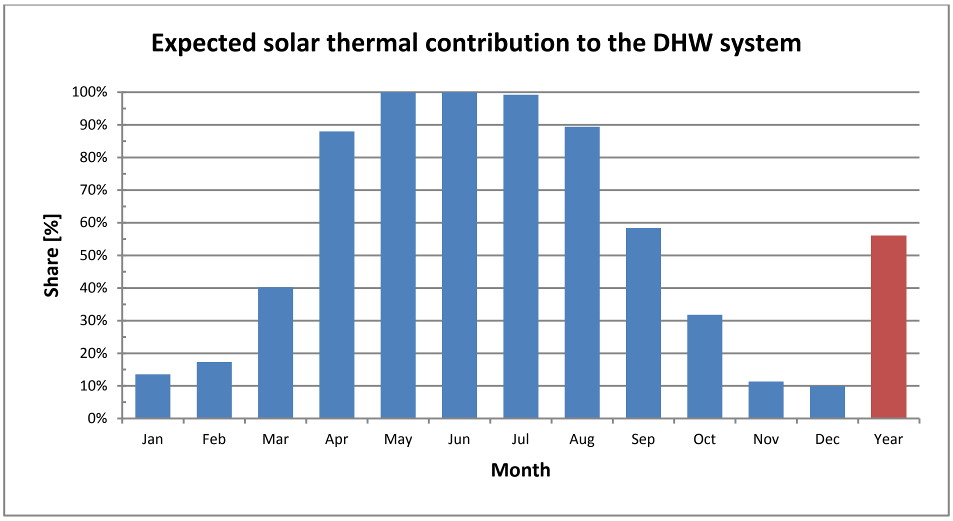


Figure 13 - Expected solar contribution of the solar thermal system to the DHW system (%)

5.3.3 Energy Efficiency

5.3.3.1 Electricity Storage

In case of emergencies and peak periods, autonomy from the grid is desirable. Because usually, in the case of PV, the time of greatest demand is during the period of lowest or null production, electricity storage in the form of batteries can help decouple production and demand. In the Netherlands, power outages in the LV network occur once every three years, approximately. When this happens, power is usually restored within four hours. The amount of storage needed for four-hour autonomy for a single household in case of an outage will be calculated based on a minimum load; i.e., lighting, a TV and a computer. On average, a Dutch household has 43 lamps [44]. Assuming only 70% of them will be in operation during the outage period, and that they are all 8W energy saving lamps, the lighting load will be 240W. A 32"LCD TV and cable box consume around 100W and 35W, respectively, whilst the laptop computer is assumed to consume 90W.

The total load in one hour then, is 465 W. The storage capacity required for four hours, then, is 1.86 kWh. Assuming a 50% discharge of battery capacity to preserve battery life and 10% energy conversion losses, the battery capacity should be around 4kWh. For a 12V battery, the ampere-hour capacity requirement is 334 Ah. For a 24V battery bank, the ampere-hour capacity requirement is 167 Ah. This can be satisfied with four 1020 Wh Amstron 12V, 85Ah sealed lead acid batteries, for instance.

5.4 Network Design

5.4.1 Network topology

Most LV power distribution systems are designed to be radial, i.e., each feeder serves a specific service area via a single path between each customer and the substation. If the path is interrupted by the failure of one of the system's components, the customer will suffer complete loss of power. In order to avoid this problem, some radial distribution systems are laid out and constructed as a meshed network, but operated in radial mode by means of open switches at certain nodes in the network configuration. This, however, increases the cost and degree of complexity of the grid's planning, design and operation.

If well designed and constructed, radial networks will provide very high levels of reliability. The additional costs associated with operating a more reliable configuration are economically unfeasible for all but the absolutely critical loads (e.g., hospitals, important municipal facilities, the utility's own control center) [45].

With the above in mind, it is no surprise that the preferred topology of NV RENDO's new networks is radial. The benefits of such configuration added to the high reliability inherent to the Dutch electricity grid (one four-hour outage every four years at LV level) [46], make a radial configuration for the De Schans LV network a suitable solution that combines economic feasibility, ease of operation and reliability.

5.4.2 Conductors

Cables should be 4×150 Al, and should generally not exceed a length of 350m. If the length is longer, the fuse rating and grounding of the conductor should be lowered in order to protect the cables in case of a fault. 30-40 connections per conductor are a normal amount by industry standards.

5.4.3 Technical considerations

Some technical criteria are outlined below:

- To ensure adequate voltage levels at the end nodes (between 207V and 253V for 95% of the time, in compliance with the Dutch grid code), the LV bus bar voltage should generally not be lower than 230V.
- Acceptable MV bus bar ranges are 9500-10750 V.
- The nominal short-circuit current of the Steenwijk MV network is 7.5-8.1 kA.
- All connections should have a neutral-ground coupling, and the grounding resistances should be 1 Ohm for the LV bus bar, 1.5 Ohms for the end nodes, and 166 Ohms for the house installations.

5.4.4 Network design

The proposed network layout is schematically depicted in Figure 14 below. The distribution cables are color-coded in the figure according to transformer station to which they are connected. This final layout is the product of a couple of design iterations. Please refer to Appendix D for discarded designs and additional information.

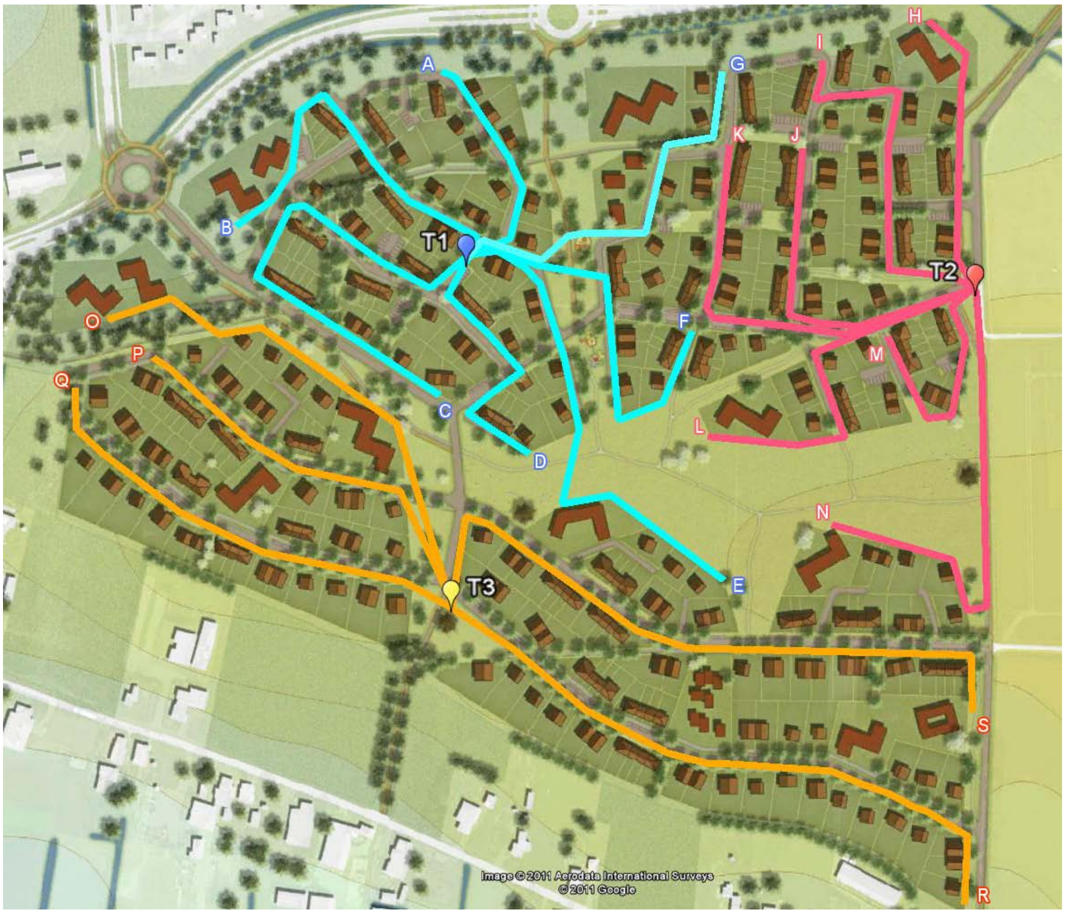


Figure 14 - Schematic representation of the proposed LV distribution network

The LV distribution system for De Schans consists of three MV/LV substations, each housing a 630 kVA 5-tap transformer (10250/400V), which will service the 400 houses via a total of 19 radial feeders. The transformers' expected share in the De Schans's Energy distribution system, based on the number and types of loads they service, is depicted in Figure 15. For calculations of these shares, please refer to Appendix D.

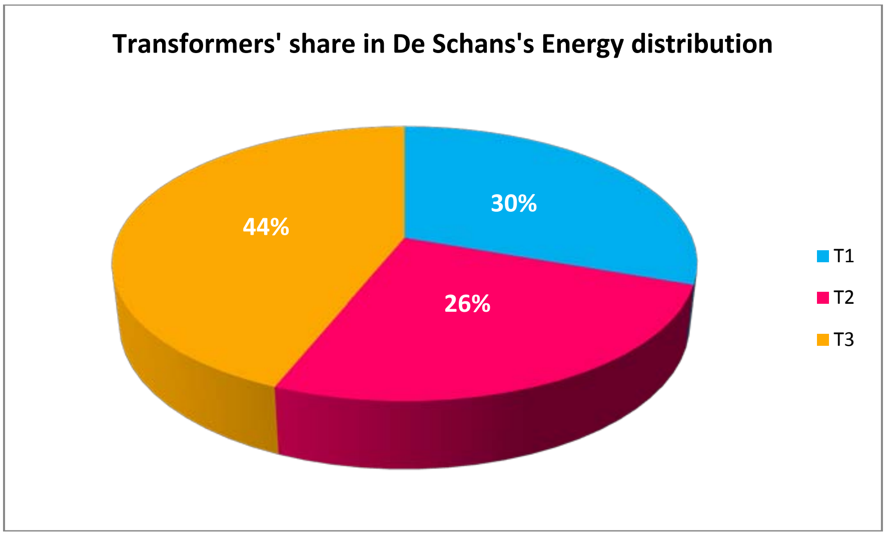


Figure 15 - Transformers' share in De Schans's energy distribution

The distribution cables selected for this application are ALKUDIA 4×150 Alh conductors, with nominal voltage 750 V and nominal short-circuit current 260 A. All houses are given three phases and have a neutral-ground coupling resistance of 166 ohms. The cables' lengths and estimated peak loads with no DG or special loads connected to the network are tabulated in Table 7.

Table 7 - LV distribution cables and loads

Cable name	From	To	Length [m]	Connections[10]				Per conductor phase	
				T	S	D	A	Peak load[11] [kW]	I [A]
C01	T1	A	165	3	0	8	0	8.16	35.46
C02	T1	B	275	12	4	3	6	14.24	61.91
C03	T1	C	340	16	6	2	0	13.00	56.52
C04	T1	D	195	7	2	4	0	8.79	38.24
C05	T1	E	340	0	4	5	4	9.34	40.61
C06	T1	F	280	10	2	3	0	9.57	41.61
C07	T1	G	275	4	0	4	14	12.06	52.45
C08	T2	H	195	4	2	1	5	7.84	34.08
C09	T2	I	265	14	6	4	0	14.17	61.61
C10	T2	J	240	9	4	5	0	11.63	50.55
C11	T2	K	300	8	6	1	0	8.78	38.15
C12	T2	L	270	4	2	2	4	8.33	36.23
C13	T2	M	175	7	4	1	0	7.51	32.65
C14	T2	N	350	0	2	3	4	6.78	29.48
C15	T3	O	350	0	0	4	11	8.44	36.70
C16	T3	P	275	11	8	3	5	15.67	68.14
C17	T3	Q	313	9	10	10	2	58.42	84.67
C18	T3	R	435	12	12	18	8	86.77	125.76
C19	T3	S	465	23	16	4	9	79.57	115.32

[10] T = terraced houses, S = semi-detached houses, D = detached houses, A = apartments
[11] Houses modeled as Strand-Axelsson loads. For calculations, see Appendix D.

Chapter 6
Simulations and Results

6.1 Building Performance after Energy Savings

6.1.1 Preliminaries

In order to determine the extent to which the energy saving measures discussed in Sections 3.1 and 5.1 can reduce the space heating demand of the buildings, first it is necessary to define and model a base case for each type of dwelling. The model inputs and outputs for such a base case can be found in Appendix B. In this section, the proposed changes and energy efficient measures from Sections 3.1 and 5.1 will be added onto the base case to quantify/estimate how much energy can actually be saved and determine the new heating demands of the buildings.

Simulations in both Appendix B and this section were done in CASAnova, an educational software developed by the University of Siegen that estimates heating and cooling demands of buildings based on the interactions among different building envelope parameters such as geometry, orientation, fenestration, thermal insulation, building mass, internal gains, climate, and energy [17]. CASAnova allows the user to adjust the aforementioned parameters by manipulating scrollbars and selecting options from drop-down menus. All parameters are grouped into six categories: geometry, fenestration, insulation, building, climate, and energy. From these parameters, outputs regarding heating and cooling energy flows are calculated by the software and displayed on-screen.

6.1.2 Climate

A climate data file specifically tailored to the Steenwijk region was created and imported into CASAnova for the simulations. Said file consists of a yearly set of hourly values for outdoor air temperature, as well as total and diffuse radiation on a horizontal plane. These were obtained by averaging three years' worth of data (2008-2010) from the closest KNMI meteorological station, Hoogeveen [42]. A chart of monthly average temperature values can be found in Appendix B.2.1.

6.1.3 Geometry

Dimensions stay the same in all cases, except for the detached house, where the roof ridge is oriented east-west instead of north-south in order to accommodate for PV panels, as discussed in Section 5.3.1.

6.1.4 Fenestration

The optimality of solar gains through the south glazing was evaluated for the base case. The ratio between the solar glazing and floor areas for all four types of dwellings are shown in Table 8:

Table 8 - Solar glazing ratio [-] per type of building, base case

	Terraced	Semi-detached	Detached	Apartment
Solar glazing area [m²]	10.56	11.68	14.08	6.88
Floor area [m²]	124.60	147.60	169.20	81.70
Solar glazing ratio [-]	**0.085**	**0.079**	**0.083**	**0.084**

These values fall short of the recommended minimum ratio of 0.13 discussed in Section 5.2.1. For an improved passive solar heating design, the south-facing windows need to be resized in CASAnova as per Table 9:

Table 9 - Minimum required south-facing window area for optimum passive solar gains

	Terraced	Semi-detached	Detached	Apartment
Required solar glazing area [m²]	16.20	19.19	22.00	10.62
Including frame [m²]	20.25	23.99	27.50	13.28
As fraction of wall [%]	61.36	65.71	62.63	61.46

The expected SSF from this redesign are 40%.

Increasing the glazing areas of the houses has no effect on the primary energy demand for heating. Because the windows' U-values are still relatively high, the increased solar gains brought on by a larger glazing area are lost by transmission through those very windows.

Improving the windows' thermal performance is essential for cutting back on these transmission losses. This can be achieved by utilizing high-transmission, low-emissivity glazing with a U-factor of 1.42 W/(m²K) and an SHGC of 0.58. The operable window frame has a U-value of 1.5 W/(m²K). The increased solar gains reduce the buildings' primary heating energy demand by approximately 8.6% on average with respect to the base case.

However, the increased usable solar heat gains have a direct impact on the overheating hours of the building, almost doubling the cooling demands with respect to the base case. This negative effect can be counteracted by placing shading devices in the southern-facing windows during the summer months to block unwanted solar heat gains. For example, if retractable awnings are installed, they will shade approximately 75% of the glazing area [19], and reduce the amount of overheating hours in the buildings by approximately 85%.

6.1.5 Insulation

The houses were fitted with insulation whose U-values correspond with the recommended values from Section 3.1.2. The walls and floor of the terraced, semi-detached and detached dwellings have an overall heat transfer coefficient of 0.30 W/(m²K), while the U-value for the roof is 0.19W/(m²K). In the case of the apartment, U-values for the walls and floor are set at 0.25 W/(m²K), representing no change with respect to the base case. The U-values of the ceiling of the apartment are also modified to the minimum recommended value of 0.19 W/(m²K).

All shared walls in the terraced and semi-detached houses, as well as the apartments, are assumed to be adiabatic. Furthermore, it is assumed that the constructions have been fitted with thermal breaks at all structural members between outside and inside surfaces to reduce thermal bridging.

As the insulation of the dwellings is improved, so does their thermal performance, as the heating energy demands further decrease by 15% on average.

6.1.6 Building Envelope Heating and Cooling Loads

6.1.6.1 **Thermal Comfort**

For the sake of energy efficiency, the comfort set-point for heating will be decreased by 1°C, from 20°C to 19°C. This 1°C difference translates into very significant energy savings of slightly more than 10%.

6.1.6.2 **Thermal Mass**

The thermal mass of the buildings will be increased by covering the internal walls with PCM plaster. A 15-mm layer will add 20.1 kJ/(m²K) thermal capacity to the walls, setting the interior envelope's characteristic thermal capacity to 85 kJ/(m²K). However, this value is not possible to model in CASAnova due to the software's limitations, because only three types of construction can be modeled: lightweight and heavy (with 25, 65 and 105 kJ/(m²K) characteristic thermal capacities, respectively). In order to model a heavy interior construction, that means that a 30-mm PCM plaster layer needs to be used instead of the design proposed in Section 5.2.2. The external walls will stay as medium constructions. The overall impact of this measure translates into energy savings of approximately 4.5%.

6.1.6.3 **Internal Gains**

The internal gains stay the same as the base case, as there are no changes in the number of occupants, equipment and lighting present in the dwellings.

6.1.7 Ventilation

6.1.7.1 **Mechanical Ventilation**

The buildings modeled in the base case are already tight constructions, so the infiltration rate input for the simulations stays the same. A balanced mechanical HRV system with a bypass damper for the summer months will be installed instead of the traditional mechanical ventilation system. The heat recovery efficiency of the system is 90%. The individual contribution of the ventilation system to the overall energy savings in the building is approximately 24%.

6.1.8 Energy Performance

The energy performance of each type of house in terms of heating, cooling and neutral-energy hours is depicted in Figure 42 below and compared against the reference case in Appendix B.3. The term "heating hours" refers to the time period during which the room temperature is below the thermal comfort set point, thus requiring the heating system to be turned on; "zero energy hours" are the time period during which room temperature lies between the set comfort range without any need for heating or cooling; and "cooling hours" are the time periods during which indoor temperature is above the overheating limit, thus creating a demand for air conditioning. Because there is no cooling system in the current setup, the building will be overheated in the summer months.

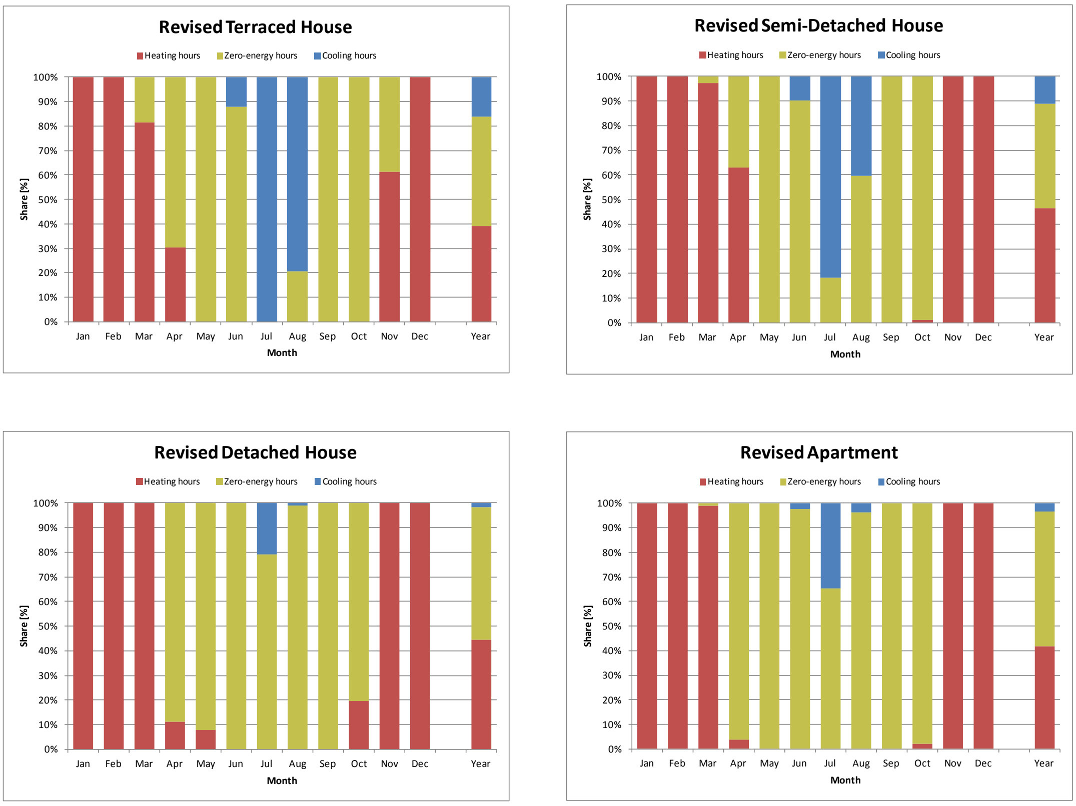


Figure 16 - Building performance for the reference houses in terms of energy hours

The redesign of the building envelope has a very positive impact on the time periods when the dwellings' indoor temperatures are at a comfortable level without the need for the heating system to be running. It also almost completely eliminates the cooling loads, especially in the detached house and apartment. Such low cooling loads make the installation of a dedicated cooling system unnecessary, without there being too much sacrifice of comfort for the occupants.

Table 10 - Building performance of the reference and revised dwellings: share of energy hours per year [%]

	Base case			Revised design		
Type of dwelling	**Heating hours per year [%]**	**Zero-energy hours per year [%]**	**Cooling hours per year [%]**	**Heating hours per year [%]**	**Zero-energy hours per year [%]**	**Cooling hours per year [%]**
Terraced	51	28	21	39	45	16
Semi-detached	54	28	18	46	43	11
Detached	59	29	12	45	53	2
Apartment	58	33	9	42	55	3

Energy demands for heating per month, per type of dwelling, can be seen in Figure 17. The total heating demands of the proposed design, per type of household, and the energy savings with respect to the base case are shown in Table 11 below:

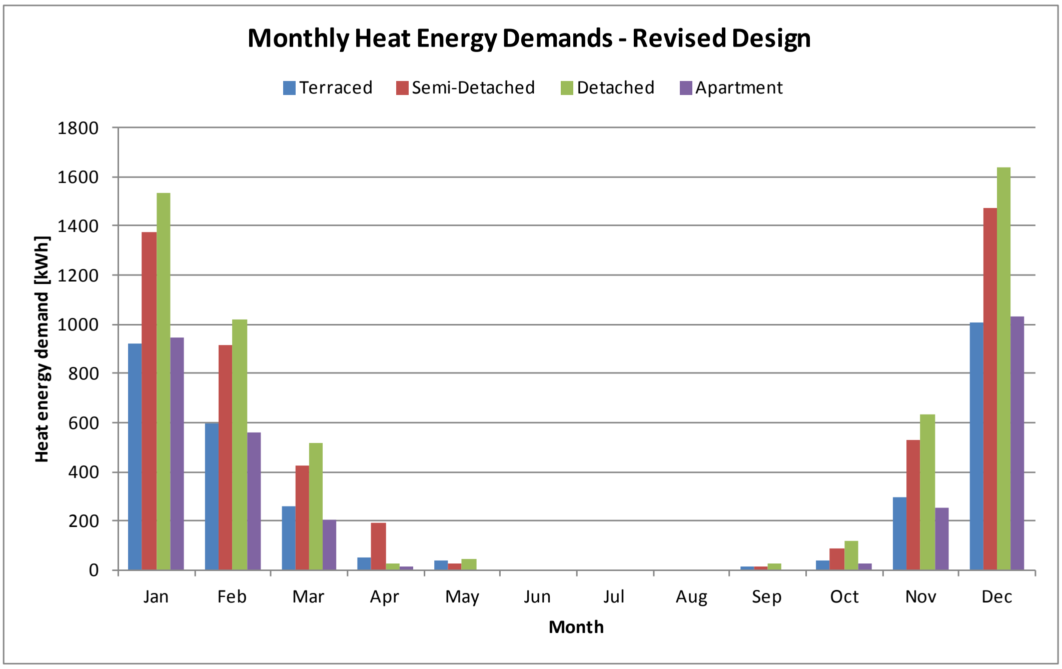


Figure 17 - Heat energy demands, revised design

Table 11 - Heating demands and energy savings

Dwelling Type	Heating demand [kWh/a]		Energy savings
	Base case	Proposed design	
Terraced	7612	3227	**58%**
Semi-detached	10796	5048	**53%**
Detached	13342	5565	**58%**
Apartment	4656	3041	**35%**

6.1.9 Primary energy demands

Three scenarios for the heating system will be studied: 1) high-efficiency natural gas boiler with a high-temperature radiator system; 2) CHP district heating fueled by 80% natural gas and 20% green gas; and 3) geothermal heat pump. Case 1 will have a high-temperature radiator system, to compare against the base case, and cases 2 and 3 will be equipped with low-temperature underfloor heating. Primary energy demand for heating is calculated in CASAnova by:

$$\begin{matrix}\text{Primary}\\\text{energy}\\\text{demand}\\{[\text{kWh/m}^2\text{a}]}\end{matrix} = \left(\begin{matrix}\text{Heat}\\\text{energy}\\\text{demand}\\{[\text{kWh/m}^2\text{a}]}\end{matrix} + \begin{matrix}\text{Losses}\\\text{(storage,}\\\text{distr., trans.)}\\{[\text{kWh/m}^2\text{a}]}\end{matrix}\right) \times \begin{matrix}\text{Expense \#}\\\text{of heat}\\\text{generation}\\{[-]}\end{matrix} \times \begin{matrix}\text{Primary energy}\\\text{factor of}\\\text{heating [-]}\end{matrix} + \begin{matrix}\text{Auxiliary}\\\text{energy}\\\text{demand}\\{[\text{kWh/m}^2\text{a}]}\end{matrix} \times \begin{matrix}\text{Primary energy}\\\text{factor of aux.}\\\text{system [-]}\end{matrix} \quad (3)$$

The heat energy demands are an output of the simulation. Losses for storage, distribution and transmission, and auxiliary electricity demands all depend on the type of heating system and the type of dwelling, and are computed by CASAnova. The expense numbers and primary energy factors of the heat generation are based on the German norm DIN 4701-10, and can be found in Table 12. The primary energy demands for each type of house and heating system can be found in Table 13.

Table 12 - Expense numbers and energy factors of the heating system solutions

Heating System	Energy Source	Expense # [-]	Primary Energy Factor[-]
HR boiler	natural gas	0.98	1.1
geothermal heat pump	electricity	0.23	3
district heating CHP	80% natural gas 20% green gas	1.01	0.56

Table 13 - Primary energy demands per type of dwelling and heating system solution

	Primary energy demand for heating [kWh/m²a]		
Dwelling Type	**HR Boiler**	**Geothermal Heat Pump**	**District heating CHP with Green Gas**
Terraced	38.6	33.3	24.7
Semi-detached	46.7	37.1	27.8
Detached	49.5	38.4	28.9
Apartment	34.6	31.4	23.2
Savings with respect to base case	**49%**	**58%**	**69%**

In any case, the 30% curtailment design benchmark set in Section 5.1.1 is satisfactorily met and surpassed. The dwellings' rated thermal performance is even close to Passivhaus standards. As for the optimal heating system for the dwellings, district heating CHP with green gas seems like the best solution, in terms of energy efficiency and infrastructural feasibility. Given the large electrical loads of the geothermal heat pumps, it is very likely that a 100% penetration level of the heat pumps cannot be achieved, especially if combined with PEVs. This situation will be looked into in more detail in the paragraphs dedicated to network simulations.

6.2 Network Simulations

Network simulations were carried out in Gaia LV Network Design, from Phase to Phase BV, an Arnhem-based IT company specialized in calculation software for electricity transmission and distribution networks. A tool for network planning, Gaia is used to determine component loads and ensure voltage management via stochastic load flow calculations.

6.2.1 Network components

6.2.1.1 Sources

The existing MV network in Steenwijk is modeled as an infinitely strong network in Gaia, represented by ideal voltage sources connected to the MV bus bars at the primary of the transformers. The nominal voltage of the sources is 10.25 kV, with lower and upper bounds of 10.0 and 10.5 kV, respectively; and the rated short-circuit currents are set to 8.1 kA, as per specifications of the Steenwijk MV network, delimited in Section 5.4.

6.2.1.2 Transformers

Three 5-tap transformers of 630 kVA rated apparent power are selected from the Gaia transformer catalog (630 10250/400 5f R). Nominal voltage at the primary side is 10250 V and 400V at the secondary. Connections on both sides of the transformers are symmetric.

6.2.1.3 **Nodes**

The three MV bus bars at the primary of the transformers have a nominal voltage of 10.25 kV; and the nominal voltage of the LV bus bars at the secondary is 230 V.

6.2.1.4 **Conductors and their Loads**

Nineteen new Alkudia 4*150 Alh+4*6+As50 cables are selected from the Gaia catalog to connect the loads to the LV bus bars of the three distribution stations. The number, types and distances of the loads connected are in accordance with Section 5.4.4. All houses were evenly distributed along the cable lengths according to the map layout, and given all three phases of the conductors. Their neutral-to-earth grounding resistance was set to 166 Ohm. For load flow calculations, a worst-case load growth rate of 2% —larger than the EC predicted growth rates discussed in previous chapters— was used.

A schematic of the network is depicted below. For a larger blueprint, please refer to the end of this report.

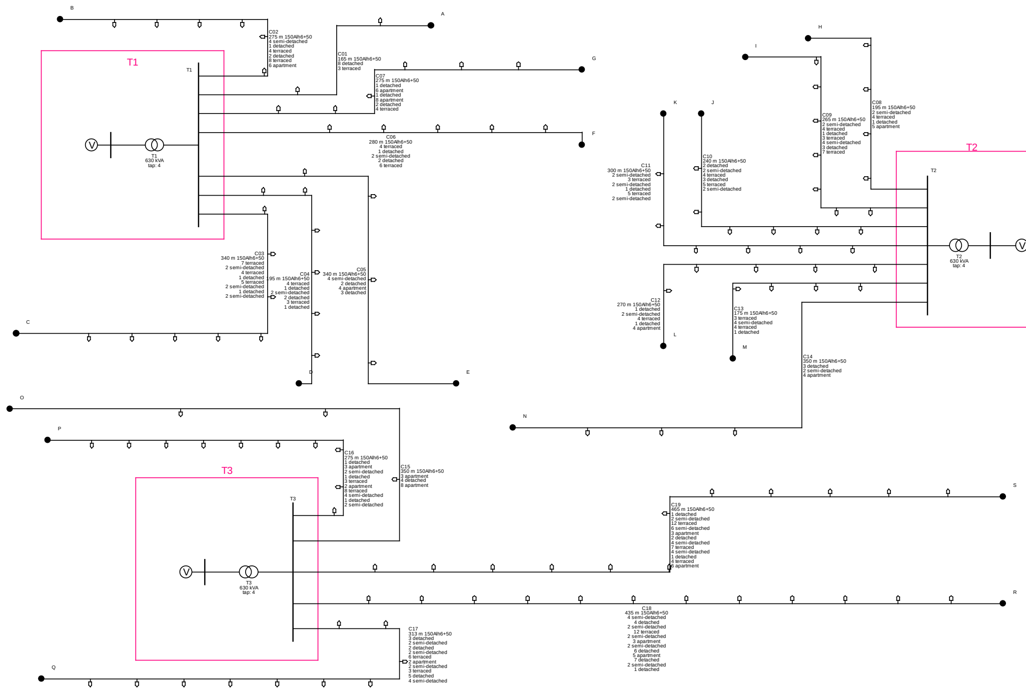


Figure 18 - De Schans LV distribution network configuration in Gaia

6.2.2 Base Case

The base case refers to the network performance with no DG or special loads (i.e., heat pumps and EVs) connected. This network load flow simulation was done for a twenty-year period. Results from year 20 are displayed below. In this simulation, the cable loadings were taken as constant, with values equal to the peak load values from the Strand-Axelsson calculations.

6.2.2.1 **Node voltages**

The voltage bands at every node are graphed in Figure 19 below. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines.

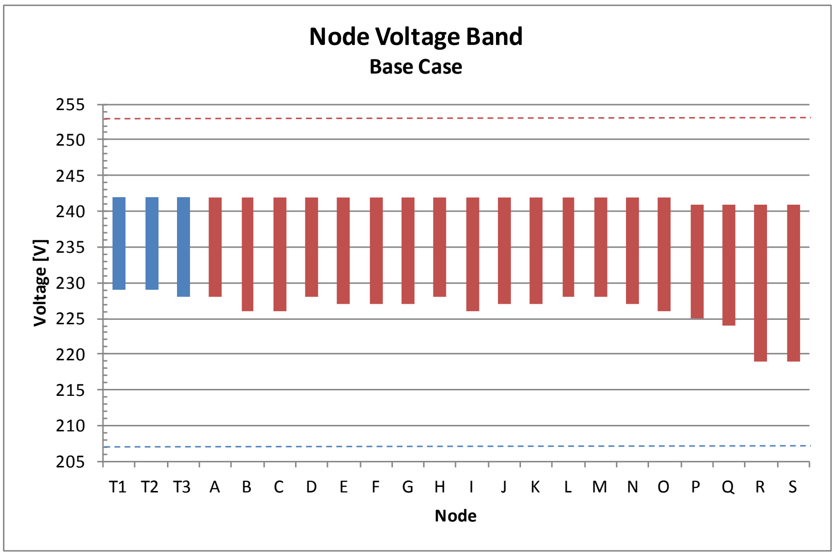


Figure 19 - Gaia simulation results: Node voltages, base case

It is evident from the diagram that the voltage drop experienced in all nodes falls well within the ±10% range. The nodes most sensitive to voltage drop are R and S, as they have the greatest cable lengths and connect the largest number of loads.

6.2.2.2 Transformer and cable loadings

Branch currents, expressed as load percentage, of all cables and transformers are graphed in Figure 20.

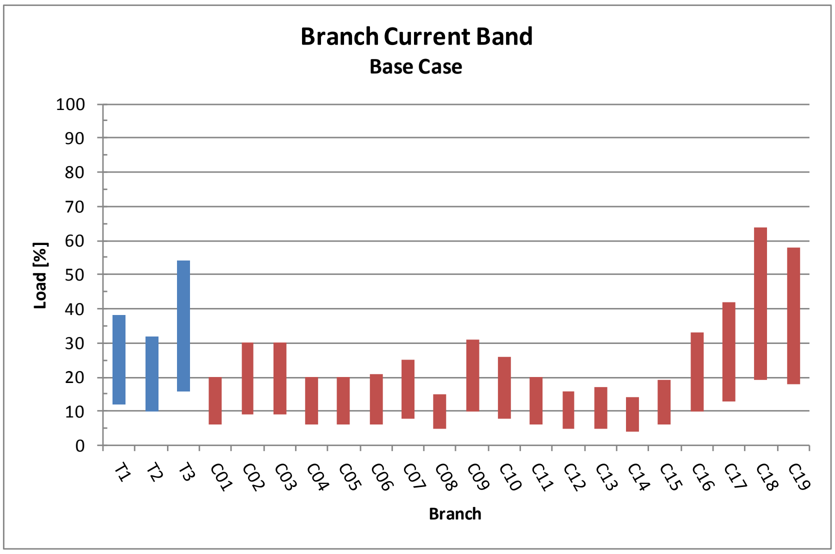


Figure 20 - Gaia simulation results: branch currents, base case

While all branches are able to cope with the loads to which they are subjected, it is possible that, when connecting DG and special loads, transformer 3 and branches 18 and 19 might not be able to withstand the additional stress to the system.

In summary, the proposed network is acceptable, given the node voltages and branch currents are all within the defined tolerances. Potentially, there could be problems with cables 18 and 19 when connecting DG and special loads, as they have the most connections, and the heaviest loads to boot (i.e., the most detached homes). In the following paragraphs, the results of simulations done with DG and/or special loads connected to the network will be discussed.

6.2.3 PV Systems

To evaluate the effects of the PV systems on the grid, two worst-case scenarios will be discussed: one at the time of maximum PV production and minimum load, occurring in the summer; and one at the time of minimum PV production and maximum load, occurring in wintertime.

For this case study, the house loads were modeled in accordance with the summer workday and the winter weekend profiles found in Appendix E.1. PV production for each house was modeled in Gaia as a negative load and given the same profiles that were derived in Section 5.3.1. The PV loads were divided symmetrically among the three phases of the conductors. The network load flow calculations were carried out by analyzing the interactions of the different load profiles in the network for a period of 20 years.

6.2.3.1 **Maximum PV production, minimum load**

Node voltages

In order to show the effect of PV on node voltages, the installed capacity of PV per node is depicted in Figure 22 below.

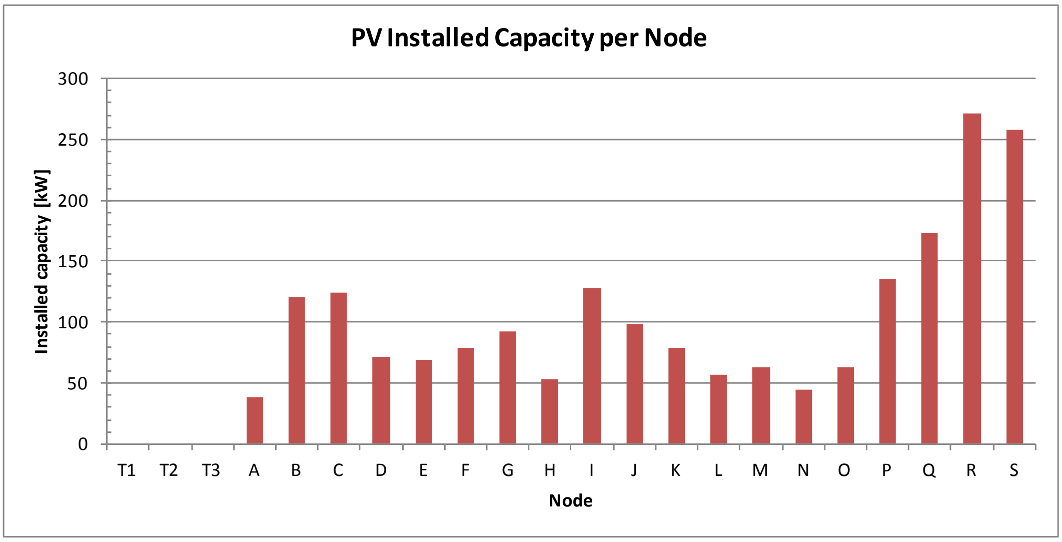


Figure 21 - PV installed capacity [kW] per node

The voltage bands at every node are graphed in Figure 22. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines.

It can be seen that although there is considerable voltage rise in the nodes due to the PV production, the voltage levels fall within the allowed limits under the most extreme circumstances.

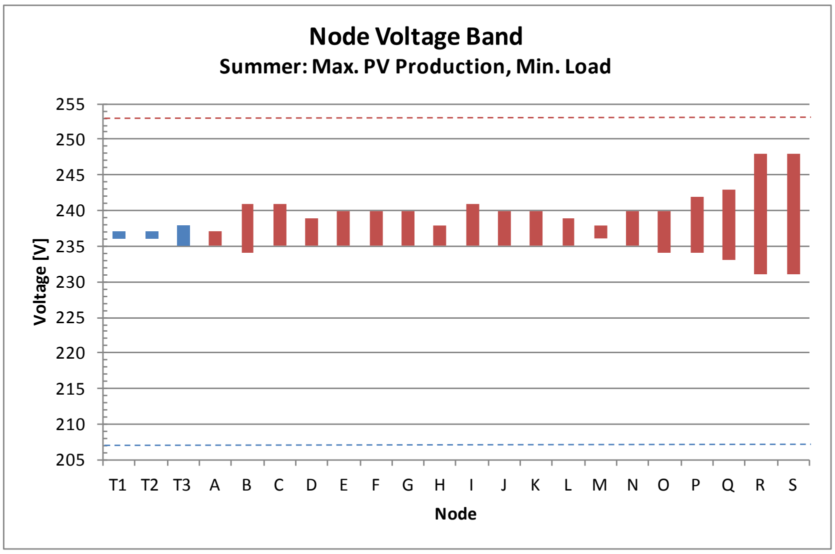


Figure 22 - Node voltages, max. PV production, min. load conditions

Transformer and cable loadings

Branch loads for this scenario are shown in Figure 23.

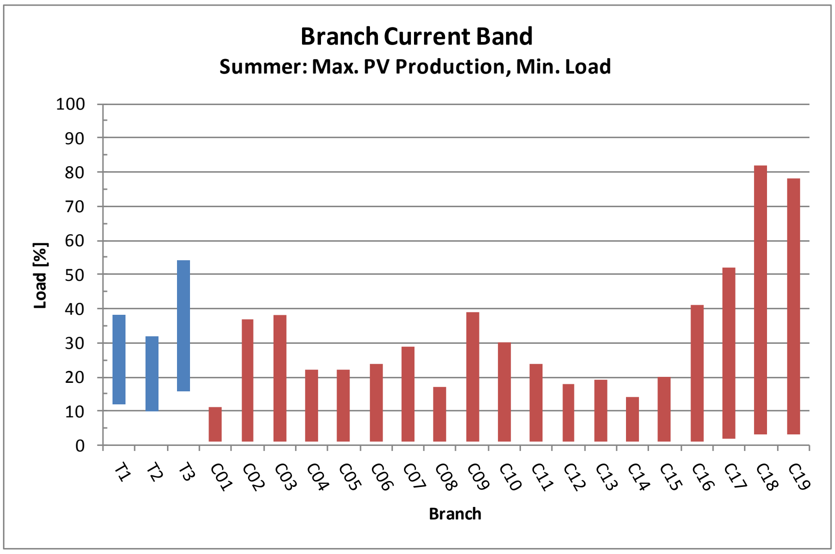


Figure 23 - Branch currents, max. PV production, min. load conditions

Under these circumstances, the transformer and cable loads are within the acceptable limits. Nevertheless, potential problems could arise in cables 18 and 19 given that they are more heavily loaded than the rest of the branches.

6.2.3.2 Minimum PV production, maximum load

Node voltages

The voltage bands at every node are graphed in Figure 24 below. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines.

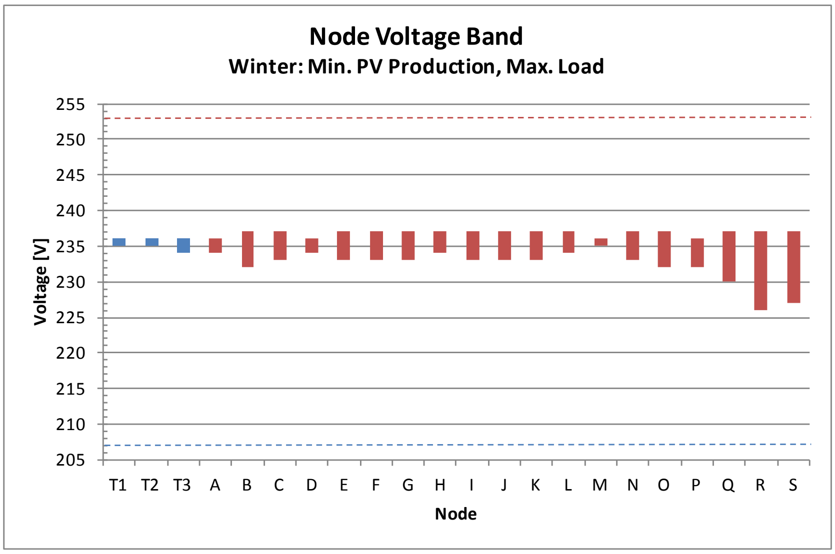


Figure 24 - Node voltages, min. PV production, max. load conditions

The voltage drop experienced in the nodes is still not a problem because it falls between 230 V ±10%. PV has a minimal, if negligible, influence on the network, given the production levels during winter are so low. The influence of PV on the network can be seen as a brief voltage spike at around noon in Figure 25.

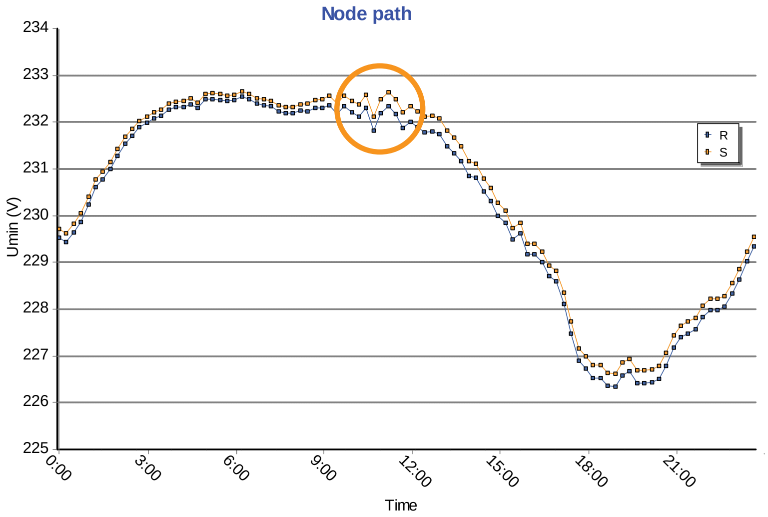


Figure 25 - Voltage drop profile, Nodes R & S, winter PV scenario

Transformer and cable loadings

Branch loads for this scenario are shown in Figure 23, and once more, all of them are within acceptable limits. Again, transformer T3 and cables 18 and 19, being the most heavily loaded, could present a problem when incorporating EVs into the network, especially because the peak period coincides with the time people come home for the evening and start charging their cars.

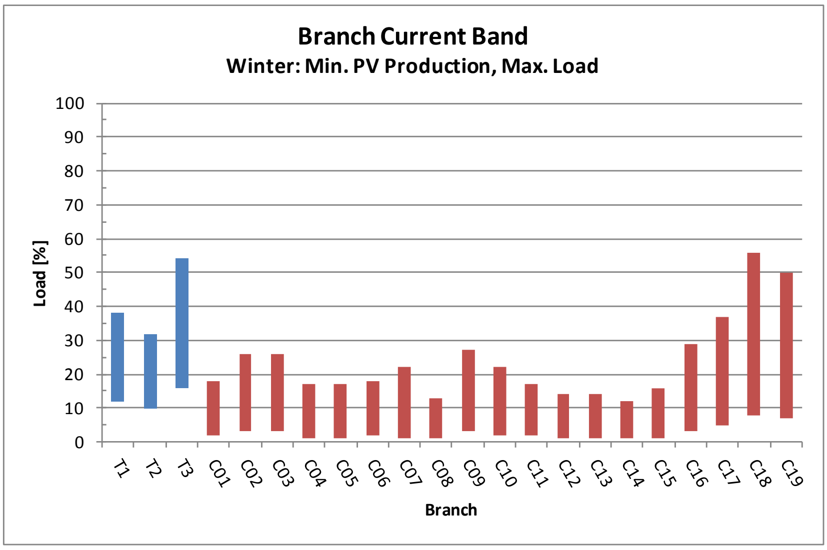


Figure 26 - Branch currents, min. PV production, max. load conditions

6.2.4 Electric vehicles

The objective of these simulations is to assess the level of EV adoption without exceeding the peak capacity of the network. The EV fleet for De Schans is modeled in Gaia as a constant-current load on each of the end nodes, and added to the existing PV network. The two EV load profiles from Appendix E.2.1 (charging after work) were used for the simulations. The magnitude of the loads in each node is set at 3.3 kW per vehicle, assuming a 40% adoption level among the households.

6.2.4.1 **Charging after work**

For this scenario, it is posited that most people will arrive home from work at 18.00h with a difference of more or less half an hour.

Node voltages

The voltage bands at every node are graphed in Figure 27 below. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines.

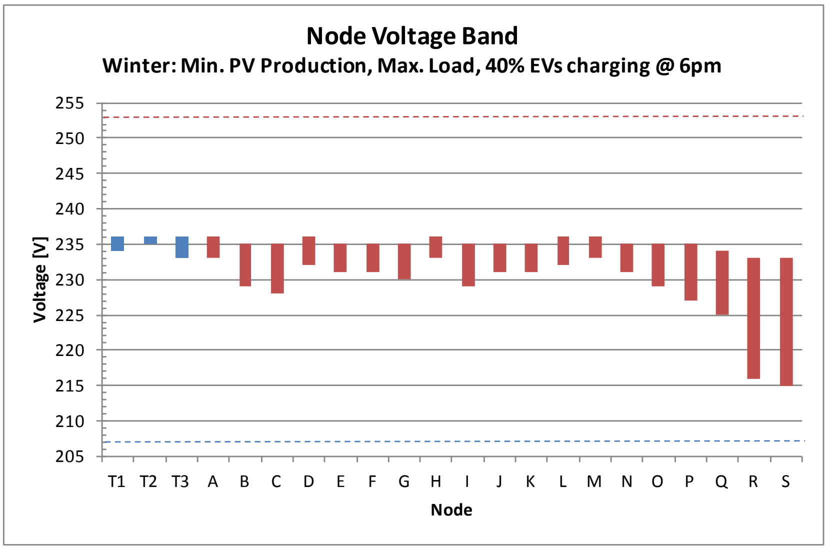


Figure 27 - Node voltages, min. PV production, max. load, 40% EV charging at 6pm

The voltage drops significantly as a result of the additional stress of connecting the EVs, but the node voltages are still within acceptable limits.

Transformer and cable loadings

Branch loads for this scenario are shown in Figure 28. The transformers and cables are very heavily loaded due to the fact that the EVs are charging during the peak period of electricity use in the household, adding to the peak load. Once more, transformer T3 and cables 18 and 19 are the weak points of the network, although the branch currents are still lower than their rated short-circuit currents, and could therefore be acceptable for the network in theory.

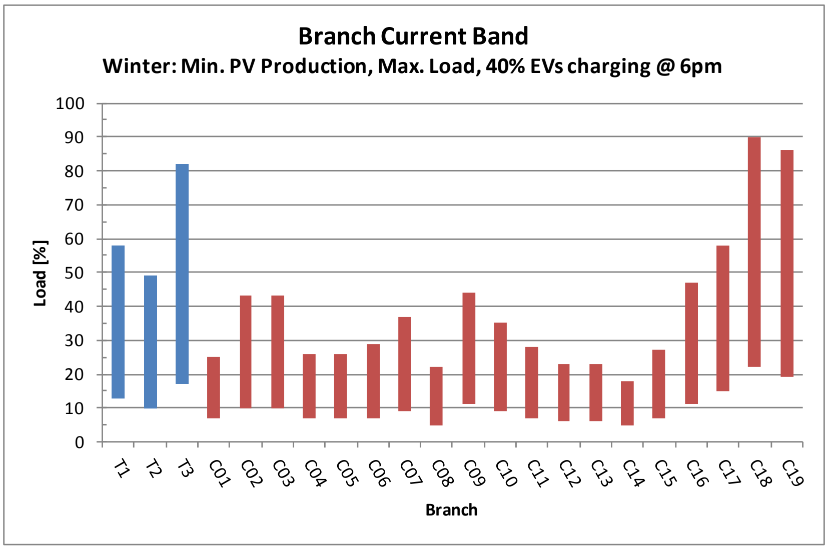


Figure 28 - Branch currents, min. PV production, max. load, 40% EVs charging at 6pm

6.2.4.2 Charging before going to sleep

For this scenario, it is assumed that most people will charge their EVs after the peak period is over, and before going to sleep, at approximately 23.00h, with a difference of more or less half an hour.

Node voltages

The voltage bands at every node are graphed in Figure 27 below. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines. Note that voltage drops fall within the allowance, and are significantly much less than in the previous case.

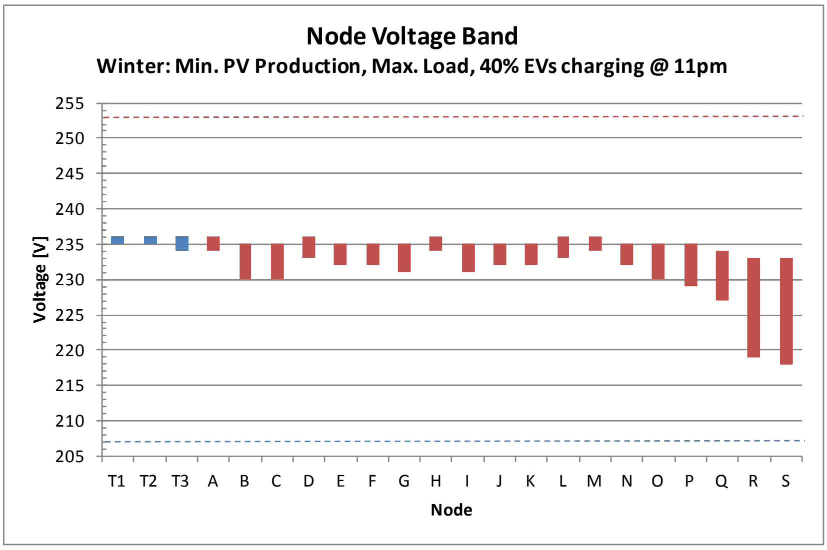


Figure 29 - Node voltages, min. PV production, max. load, 40% EVs charging at 11pm

Transformer and cable loadings

Branch loads for this scenario are shown in Figure 28.

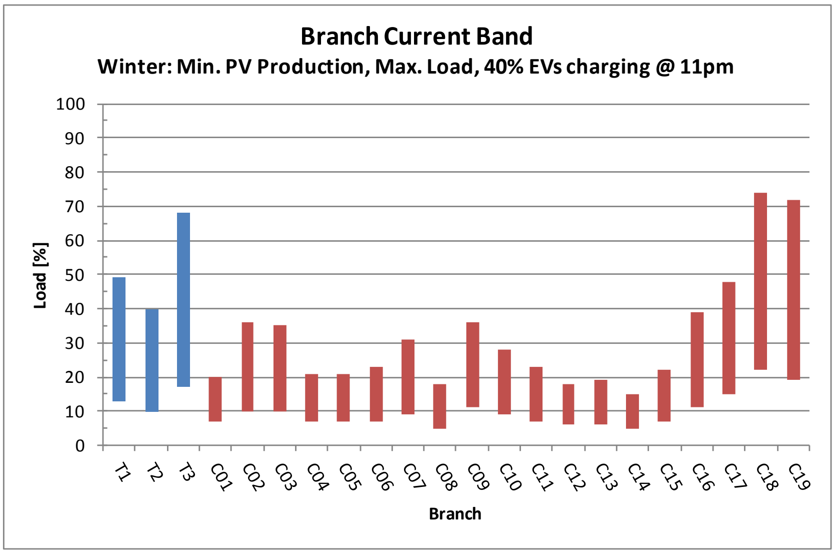


Figure 30 - Branch currents, min. PV production, max. load, 40% EVs charging at 11pm

Because the EVs started charging at the end of the on-peak period/ beginning of the off-peak period, the network branches are not as heavily loaded as in the previous scenario. This charging scheme is by far superior to the previous scenario, as it takes better care of the network components.

6.2.5 Heat pumps

The objective of these simulations is to assess the level of HP adoption without exceeding the peak capacity of the network. Therefore, a worst-case scenario of maximum electrical household loads and maximum heat pump operation to cope with the houses' heating loads will be used. Such a situation presents itself in the month of January, in which between 28-30% of the yearly heating demand is consumed. Based on the results from the CASAnova simulations, electricity demands for operating the heat pumps are shown in Table 14 below.

Table 14 - Heat pump electricity demands, worst-case scenario

	Terraced	Semi-detached	Detached	Apartment
January heat demand [kWh/mo.]	1186.0	1491.1	1791.1	798.5
Daily demand [kWh/d]	38.3	48.1	57.8	25.8

Following the heat pump load profile from Appendix E.2.2, and assuming heat storage is available and that the heat pumps operate at their maximum rated power for greater efficiency, the following peak loads are determined.

Table 15 - Heat pump peak loads, worst case scenario

	Terraced	Semi-detached	Detached	Apartment
Load [kW]	2.4	3.0	3.6	1.6

The heat pump loads modeled at the end nodes of each cable, and their magnitudes are in proportion with the number and types of houses connected to each feeder and symmetrically distributed among the three phases of the conductor. The heat pump loads were added to the previous wintertime scenario of minimum PV production, maximum household loads, and 40% penetration level of EVs recharging at 11 p.m. Because, ideally, the whole neighborhood should run on a single heating system to minimize costs related to infrastructure, a 100% penetration level of geothermal heat pumps was analyzed.

Node voltages

The voltage bands at every node are graphed in Figure 27 below. The upper and lower bounds for acceptable voltage levels according to the Dutch grid code are represented by dotted lines.

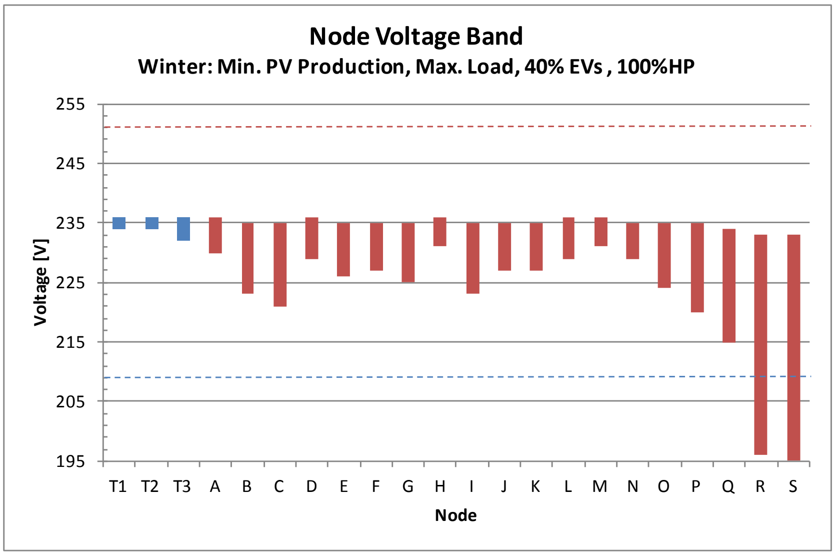


Figure 31 - Node voltages, min. PV, max. load, 40% EVs, and 100% heat pumps

Nodes R and S, the weakest points in the network, experience a voltage drop of approximately 15%, a value that infringes upon the accepted tolerances.

Transformer and cable loadings

Branch loads for this scenario are shown in Figure 28.

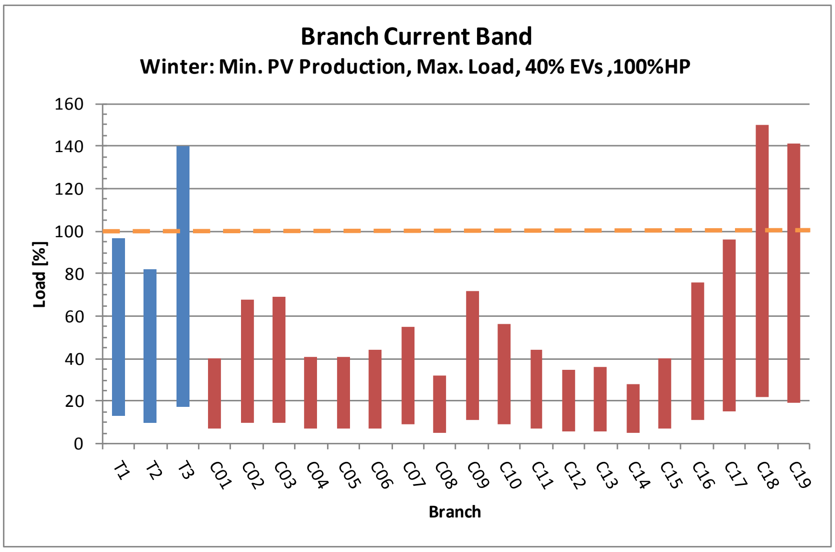


Figure 32 - Branch currents, min. PV production, max. load, 40% EVs, and 100% heat pumps

The combination of heat pumps and EVs causes an overload of the network in general:

- The transformers, if not overloaded (as is the case of T3), are operating at nearly full capacity, much to the detriment of the equipment's lifetime.
- Cables 2, 3, 9, 16 and 18, which had not been the source of problems in the previous cases, are now approaching their loading limits.
- Cables 18 and 19 are overloaded by almost 50%.

Removing the EV fleet in order to accommodate for 100% penetration of heat pumps does not solve the network problems altogether. Even though the loads on the branches emanating from transformers T1 and T2 are now within operable limits, and the voltages on their end nodes fall also within the grid code tolerances, transformer T3 and its branches are still overloaded, and nodes R and S still experience under-voltage.

Further studies reveal that a 20% adoption of heat pumps can be achieved and combined with EVs and PV without overloading the network. A higher penetration rate could be possible if the weakest points of the network are addressed, either by relocating the transformer stations for a more equitable load distribution (T3 is responsible for supplying over 40% of the neighborhood's energy demand), or by adding a fourth transformer station.

However, since it is more practical to have a single collective heating system for the whole neighborhood in terms of infrastructure, perhaps it is better to discard the option of geothermal heat pumps altogether, and go with the option of green gas-powered CHP with district heating, as it was the heating system with the greatest energy savings.

Chapter 7
Analysis and Validation

7.1 System summary

The proposed solution is schematically depicted in Figure 33. District heating CHP running on an 80/20% mixture of natural gas and green gas, as well as solar thermal collector modules placed on each house, fulfill the dwellings' primary energy requirements for heating. The PV modules placed on the roofs, used in conjunction with the LV grid as a buffer, suffice to cover the entirety of the household electrical energy needs of the neighborhood. The electrical energy demands derived from the 40% adoption rate of EVs is offset by the electricity production of the CHP.

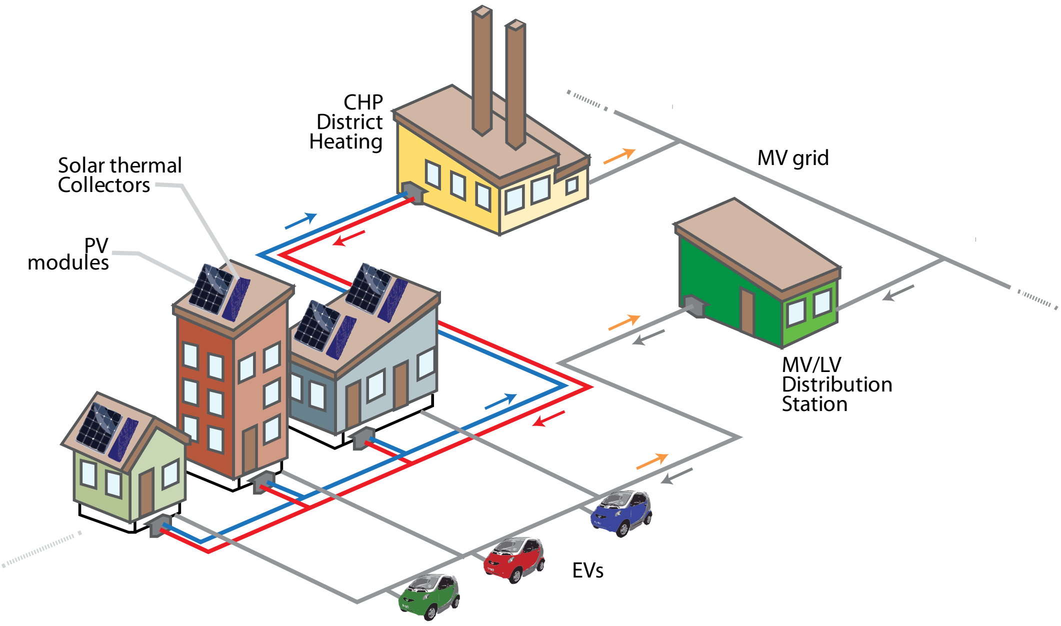


Figure 33 - Schematic of the proposed solution (Adapted from [47])

7.2 System performance: energy balance

7.2.1 Heating

The energy demands for heating of the new houses are compared against the base case in Figure 34.

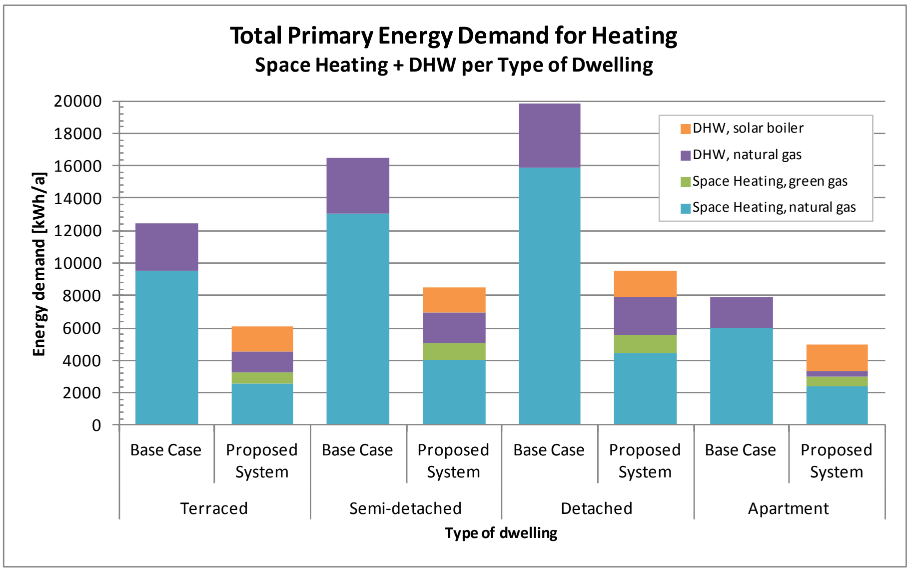


Figure 34 - Total primary energy demand for heating per type of dwelling

The improvements made in terms of the building envelope design played a key role in reducing the energy demands. For the whole neighborhood, the total primary energy demands for space heating and DHW were almost halved with respect to the base case, as it can be evidenced from the breakdown below:

Table 16 - Comparison of total primary energy demands for heating: base case vs. proposed solution

	Total Primary Energy Demand for heating [GWh]	
Application and Fuel Type	**Base case**	**Proposed solution**
Space heating, natural gas	4.42	1.31
Space heating, green gas	0	0.33
DHW, natural gas	1.23	0.60
DHW, solar boiler	0	0.63
Total primary energy demand for heating	**5.65**	**2.87**
Energy savings with respect to base case		**49%**

Even though it was not possible to achieve a net zero energy balance for heating, it is important to mention that under the current solution, 33% of the total primary energy demand will be supplied by RES, namely the solar thermal collector system for DHW and green gas mix in the district heating CHP.

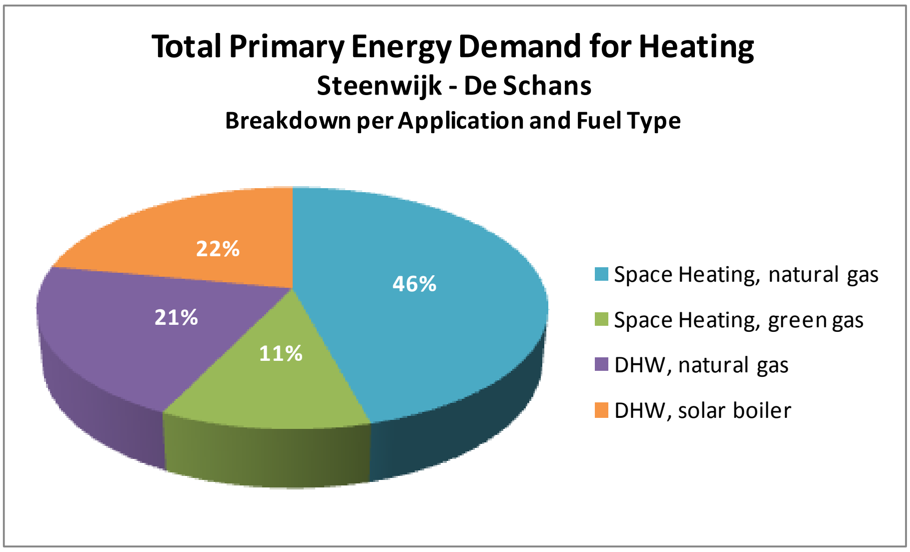


Figure 35 - Breakdown per application and fuel type of the total primary energy demand for heating

That the CHP district heating system should be able to deliver 2.2 GWh_{th} annually to satisfy the primary energy demands for space heating and DWH of the neighborhood. Peak capacity of the system should be determined according to maximum load during winter, coupled with the possibility of implementing a large-scale seasonal heat storage for the whole neighborhood. This in-depth design and dimensioning of the CHP district heating network falls out of the scope of this research project, but nevertheless is a very interesting topic for further research.

7.2.2 Electricity

For the whole neighborhood, the yearly energy balance for electricity is summarized in Figure 17:

Table 17 - Energy balance for electricity production and consumption

Application	Yearly energy demand/production [GWh]
Household electricity demand	- 1.84
EV charging demand	-0.55
PV production	1.89
CHP production[12]	1.32
Total balance	**0.82**

From this table it can be seen that De Schans is a positive energy neighborhood in terms of electricity production and usage in a balance period of one year. This positive balance could be used to offset almost half of the primary energy demand for heating being supplied by natural gas.

Table 18 - Global energy balance for De Schans

Application	Yearly energy demand/production [GWh]
Total heating demand	- 2.87
Total electricity demand	-2.39
Solar thermal DHW	0.63
CHP production, green gas	0.33
CHP production, electricity	1.32
PV production	1.89
Total balance	**-1.09**

If a global energy balance is taken, then, only 20% percent of the total energy demand of the neighborhood is not covered by RES.

Excess production can be fed back into the grid for a slight profit, depending on the available government policies regarding feed-in tariffs. In the future, this excess production could even be traded across other DG networks, with all transactions centrally managed by a VPP operator.

Who owns, manages and operates this VPP is an extremely interesting question for further research; the answers will be without a doubt driven by new opportunities brought about by the transition to the Smart Grids concept, namely the changing role of the distribution system operator (DSO) and the increasing participation of the consumer within the framework of DER.

[12] Based on the 2.2GWh thermal demand of the CHP, and assuming an 80% overall efficiency of the primary fuel, of which 50% goes to thermal energy production and 30% to electricity [90].

7.3 Network

The network simulations carried out in the previous chapter show that the proposed network design is sufficient to supply the energy needs of the neighborhood and support the production of electricity even under the worst-case conditions.

However, it is important to mention that the analyses performed in Gaia did not take system protection into account. Usually, conductors have a 224A fuse that allows for a maximum cable loading of 86%, in the case of the ALKUDIA 150Al cables used in this project. For longer cable lengths than 350m, the fuse rating is lowered to 200A, which means that the cable can have a load of up to 76%.

Taking into account the fuse ratings of the conductors, the proposed network still operates within the acceptable limits in all scenarios, except for the one with maximum PV production and minimum load, as cables R and S are loaded at 81% and 79%, respectively.

Using the battery banks to store excess PV production can result in peak shaving during this time, and can reduce the load by approximately 0.5 kW per house. For cables R and S, this translates into a peak reduction of about 25 kW per conductor, thus theoretically lowering the cable loads to 67% and 65%, respectively, which are well within the cable loading limits.

Other options for dealing with the weaknesses of transformer T3, and cables R and S, are: 1) splitting the loads from cables R and S into two to prevent overloading; 2) make T3 a higher-rated transformer; 3) relocate all the transformer stations for a more even distribution of the loads; or 4) add a fourth transformer station. This could be a problem due to the constraints of the urban planning or the additional cost of having one more distribution substation.

EVs are possible up to a 40% adoption level for charging at home without overloading the LV network, only if they are charged during off-peak hours. For higher market penetration rates or charging during on-peak periods, (fast-)charging docks at medium or high voltage should be set up by the municipality.

A similar peak shifting mechanism to the one proposed for excess PV in the summer could be applied during on-peak winter periods to offset the aggregate effect of household loads and EVs. Although it was not possible to simulate and quantify the extent of this measure on the network due to the software capabilities of Gaia's version 6.2, this could another topic for further research, especially since version 6.3, released at the end of August 2011, is now able to simulate battery storage [48].

The peak shifting mechanism of the battery storage and the charging of EVs during off-peak period, without a proper energy management system (EMS), would be very difficult and demand a lot of user intervention. Increased communication and control between DG, the grid, the storage system and the loads are needed to streamline these operations without treading on the users' comfort.

Part III

Conclusions and Recommendations

Chapter 8
Conclusions and Recommendations

8.1 Conclusions

The main objective of this research was to design a solution based on distributed energy resources to allow the De Schans development project in Steenwijk to become a net zero energy neighborhood in terms of electricity and heating. This solution was derived from a three-stage design process:

- Investigating ZEBs, passive solar design techniques and DER technologies.
- Elaborating an integrated design of the components of the building envelope and the electrical network servicing the neighborhood.
- Simulating building and network performance in order to assess the appropriateness of the design and select the most suitable heating system for the neighborhood.

The principal results and conclusions of the research are presented in the following paragraphs.

The *Trias Energetica* Design Approach

The philosophy of *Trias Energetica* used as design technique proved to be a good approach toward coming up with a viable solution for a net zero-energy balance. Reduced energy usage facilitated the use of renewable energy sources to power the demands, and enabled technologies for efficient fossil fuel consumption.

One of the initial research sub-questions dealt with the EPC as a design parameter and metric of sustainability. However, the EPC is a measure of energy efficiency regardless of energy consumption, and thus is not intended as a design parameter. That is why the project's metric of sustainability was changed to energy savings.

Importance of Passive Design in Energy Savings

Improved passive solar design proved to be the single most important driver in reducing the heating energy demand for space heating in the buildings. Larger south-facing glazing areas combined with high-transmission and low-emissivity windows, low U-value insulation materials, and a larger indoor thermal mass reduced the heating demands in the buildings by half, on average, without having to sacrifice user comfort.

Selection of the Heating System

Solar thermal collector systems provide 56% of the neighborhood's DHW demand. For space heating, district heating CHP was favored over the use of ground-source heat pumps for three main reasons. The first was because the specifications of the components of the electrical network constrained the high penetration level of heat pumps, especially when taking into account an increasing adoption level of EVs. Secondly, district heating CHP was the heating system with the highest energy savings with respect to the base case. Thirdly, a central cogeneration heating system for the neighborhood would facilitate the incorporation of locally produced biogas resources into the energy supply, as per NV RENDO's strategic roadmap for adoption of green gas into its natural gas infrastructure, and would also enable the use of natural gas in a more efficient way, as electricity is being produced as well.

Validity of the Building Simulations

The CASAnova building models, although simplistic, offer a good overview of the influence of the individual building components on the overall energy performance of each type of dwelling.

Electrical Network Performance

Network simulations point out that the LV electricity grid servicing De Schans is a strong network that allows for full deployment of a PV system sized for fulfilling the entirety of the neighborhood's electricity requirements, although PV production in the summer needs to be offset by battery storage in order to keep cable loads at appropriate levels. Additionally, this design also allows for an adoption level of EVs of up to 40%, and the battery storage enables each individual house to work autonomously for up to four hours.

Grid performance can be improved by using the battery banks to manage DG production and its exchanges with the grid, and carry out load shaving/shifting functions during on-peak demand periods. Demand-side management technologies with automatic control functions will play a major role in performing these tasks.

Final energy balance

Although the heating system of the proposed solution does not have a net zero-energy balance, primary energy demands for space heating were reduced by almost 50% with respect to the base case. Additionally, 33% of the total heating demand is supplied by RES (green gas-powered cogeneration and solar thermal collectors for DHW).

In terms of electricity, the proposed system has a positive energy. The households' PV systems, in conjunction with the district heating CHP unit, produce enough electricity in one year to compensate for the energy drawn from the grid during null PV production periods; the excess 0.8 GWh produced per year can be exchanged with the grid, or, as DG systems and micro-grids gain momentum in the future, perhaps traded among other similar nearby DER networks.

De Schans can be considered a nearly zero-energy neighborhood, because, in terms of the global energy balance, 80% of the total energy demands are met by RES.

8.2 Recommendations

The scope of this research project was quite broad, as it covered a variety of topics ranging from building physics to electrical engineering, which means that many aspects of the project were not looked into full detail. When the De Schans development project is officially given the green light to start, the stakeholders and project developers can certainly benefit from a more in-depth investigation of the separate topics discussed in this report. Some opportunities for further research include:

- Elaboration of more detailed models of the building envelope to assess building performance and cross-check the validity of the CASAnova models.
- Design and simulations in Gaia of the network protection system.
- Simulations of the battery storage systems in peak-shaving operation and autonomous modes.
- In-depth analysis and dimensioning of the district heating CHP system, taking into account peak loads, the possibility of having district-wide seasonal thermal storage, distribution losses, piping, safety, energy conversion method, and system efficiency, among other parameters.
- Study the effect of demand-side energy management devices on the system performance, in terms of peak-shifting and energy exchanges of the DG with the electrical storage systems, the grid, and other DER neighborhoods.
- Lastly, in the case of energy exchange with other DER neighborhoods, it would be interesting to see which entity will be in charge of managing these aggregate distributed generators and administering the transactions in terms of energy, money and information.

Works Cited

[1] Eric Leysen, "The trias energica: Solar energy strategies for Developing Countries," in *Eurosun Conference*, Freiburg, 1996.

[2] EC. (2010, October) European Commission Climate Action. [Online]. http://ec.europa.eu/clima/policies/brief/eu/index_en.htm

[3] Ursula Eicker, *Solar Technologies for Buildings*. Chichester: Wiley, 2003.

[4] P. Torcellini, S. Pless, and M. Deru, "Zero Energy Buildings: A Critical Look at the Definition," Battelle, Conference paper 2006.

[5] A.J. Marszal et al., "Zero Energy Building — A review of definitions and calculation methodologies," *Energy and Buildings*, pp. doi:10.1016/j.enbuild.2010.12.022, 2011.

[6] Richard Hyde, Ed., *Bioclimatic Housing: Innovative Designs for Warm Climates*. London: Earthscan, 2008.

[7] EU, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," *O.J. L*, no. 153, pp. 13-35, June 2010.

[8] SenterNovem. (2011, July) Energie data. [Online]. http://senternovem.databank.nl/Default.aspx?sel_guid=0c810167-7e29-4210-8997-64ccd65b0299

[9] Environmental Change Institute. (2006) Environmental Change Institute. [Online]. http://www.eci.ox.ac.uk/research/energy/downloads/countrypictures/cp_netherlands.pdf

[10] CBS. (2008, September) Statline. [Online]. http://www.cbs.nl/nl-NL/menu/themas/industrie-energie/cijfers/incidenteel/maatwerk/2008-2609-t.htm

[11] Stichting Passiefhuis Holland. (2006) Passiefhuis Technologie in Nederland. [Online]. http://www.passiefhuis.nl

[12] M. Elswijk and H. Kaan, "European Embedding of Passive Houses," 2008.

[13] SenterNovem. (2008) Energy Transition. [Online]. http://www.senternovem.nl/energytransition/

[14] M. Menkveld and L. Beurskens, "Renewable heating and cooling in the Netherlands," Petten, 2009.

[15] SenterNovem. (2011, July) Energie data. [Online]. http://senternovem.databank.nl/Default.aspx?sel_guid=ef4cffb5-26b0-4ea2-8162-c15d3cb2d8ba

[16] EC Directorate-General for Energy, "EU energy trends to 2030," Luxembourg, 2009.

[17] F.D. Heidt. (2007) CASAnova. Software.

[18] ASHRAE, *2009 ASHRAE Handbook - Fundamentals (SI units)*. Atlanta: ASHRAE, 2009.

[19] Walter T. Grondzik, Alison G. Kwok, Benjamin Stein, and John S. Reynolds, *Mechanical and Electrical Equipment for Buildings*, 11th ed. Hoboken: Wiley, 2010.

[20] Steve Doty, "Energy Efficiency: Strategic Facility Guidelines," in *Encyclopedia of Energy Engineering and Technology*, Barney L. Capehart, Ed. London: CRC Press, 2007, vol. 1, pp. 524-534.

[21] Clint Christenson, "Thermal Energy Storage," in *Energy Managment Handbook*, 6th ed. Lilburn: Fairmont Press, 2007, pp. 519-537.

[22] Ibrahim Dincer, "On thermal energy storage systems and applications in buildings," *Energy and Buildings 34*, pp. 377–388, 2002.

[23] M. Hill. (2011, February) ZAE Bayern. [Online]. http://www.zae-bayern.de/files/12-hill_maxit_clima.pdf

[24] DGS, *Planning and Installing Photovoltaic Systems : A Guide for Installers, Architects, and Engineers*. Sterling: Earthscan, 2008.

[25] DGS, *Planning and Installing Solar Thermal Systems: A Guide for Installers, Architects and Engineers*, 2nd ed. London: Earthscan, 2010.

[26] Martin Pehnt et al., *Micro Cogeneration: Towards Decentralized Energy Systems*. Berlin: Springer, 2006.

[27] M.G.L.C. Loomans and P.G.S. Rutten (eds.), "Reader Heat Pumps," Department of Building Physics & Systems, TU/e, Eindhoven, Study material for the course 7S815 2009.

[28] S. Parker and D. Hadley, "Ground-Source Heat Pumps Applied to Commercial Buildings," in *Energy Management Handbook*. Lilburn: Fairmont, 2007, pp. 755-791.

[29] Natural Resources Canada. (2009, April) Office of Energy Efficiency. [Online]. http://oee.nrcan.gc.ca/Publications/infosource/Pub/hrv/hrvsystem.cfm?attr=4

[30] M.G.L.C. Loomans and P.G.S. Rutten (eds.), "Reader Terminal Systems," Department of Building Physics & Systems, TU/e, Eindhoven, Study material for the

course 7S18E 2009.

[31] Dale Gustavson, Tom Lunneberg, William Cratty, and Alfred Williams, "Energy Management Control Systems," in *Energy Management Handbook*, 6th ed. Lilburn: Fairmont Press, 2007, pp. 315-353.

[32] Nedap NV (2010) The PowerRouter. [Online]. http://www.powerrouter.com/

[33] Gemeente Steenwijkerland, "Duurzaam Steenwijkerland: Duurzaamheidplan 2009-2012," Steenwijk, 2009.

[34] Gemeente Steenwijkerland, "Jaarplan Duurzaamheid 2011," Steenwijk, 2011.

[35] Gemeente Steenwijkerland. (2011, May) Gemeente Steenwijkerland. [Online]. http://www.steenwijkerland.nl/Wonen_wijken_en_verkeer/Nieuwe_ontwikkelingen/Woningbouwprojecten/Steenwijk_De_Schans

[36] BVR Adviseurs Ruimtelijke Ontwikkeling. (2010, February) Masterplan De Schans, Steenwijk vastgesteld, plan wordt nu door BVR en Onix Architecten uitgewerkt! [Online]. http://www.bvr.nl/nieuws/736-masterplan-de-schans-steenwijk-vastgesteld-plan-wordt-nu-door-bvr-en-onix-architecten-uitgewerkt.html

[37] Nieuwbouw Nederland BV. (2011) Nieuwbouw in Steenwijk. [Online]. http://www.nieuwbouw-in-steenwijk.nl/project/135/Steenwijk-De-Schans.html?t=uitgebreid#TAB

[38] J. Jonkman, "Verkenning mogelijkheden invoeding groengas op het aardgasnetwerk van NV RENDO," Meppel, Corporate report 2011.

[39] Agentschap NL. (2011, January) Ministerie van Economische Zaken, Landbouw en Innovatie. [Online]. http://www.agentschapnl.nl/content/factsheet-feiten-en-fabels-rond-aanscherping-epc-van-0-8-naar-0-6

[40] SenterNovem, "Referentiewoningen nieuwbouw," Sittard, 2006.

[41] MC Peel, BL Finlayson, and TA McMahon, "Updated world map of the Köppen-Geiger climate classification," *Hydrol. Earth Syst. Sci.*, vol. 11, pp. 1633-1644, 2007.

[42] Koninklijk Nederlands Meteorologisch Instituut. (2010) KNMI - Koninklijk Nederlands Meteorologisch Instituut. [Online]. http://www.knmi.nl/klimatologie/uurgegevens/selectie.cgi

[43] Vela Solaris AG. (2009) Polysun 5.2.0.12. Software.

[44] Milieu Centraal. (2010) Milieu Centraal. [Online]. http://www.milieucentraal.nl/pagina.aspx?onderwerp=Trend%20verlichting

[45] H. Lee Willis, *Power Distribution Planning Reference Book*, 2nd ed. Basel: Marcel Dekker, 2004.

[46] Pieter Schavemaker and Lou van der Sluis, *Electrical Power System Essentials*.

Chichester: Wiley, 2008.

[47] Rindi Energi. (2007) Rindi Energi. [Online]. http://www.rindi.se/eng/fjarrvarme.php

[48] Phase to Phase BV, "Handleiding Gaia 6.3," Phase to Phase BV, Arnhem, User Manual 2011.

[49] CBS. (2010, October) Statline. [Online]. http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLEN&PA=37312eng&D1=a&D2=0,5,8-13&HD=110407-1609&LA=EN&HDR=G1&STB=T

[50] EnergieNed, *Elektriciteitsdistributienetten*. Deventer: Kluwer Techniek, 1996.

[51] E. Lakervi and E.J. Holmes, *Electricity Distribution Network Design*. London: Peter Peregrinus Ltd., 1989.

[52] C. Gerkensmeyer, M.C.W. Kintner-Meyer, and J.G. DeSteese, "Technical Challenges of Plug-In Hybrid Electric Vehicles and Impacts to the US Power System: Distribution System Analysis," Oak Ridge, Technical Report 2010.

[53] N. DeForest et al., "Impact of Widespread Electric Vehicle Adoption on the Electrical Utility Business - Threats and Opportunities," Berkeley, Technical Report 2009.

[54] CBS. (2011, July) Statline. [Online]. http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7374hvv&D1=2-5&D2=a&D3=19&HD=110926-1754&HDR=G2,T&STB=G1

[55] CBS. (2010, November) Statline. [Online]. http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=71107ned&D1=0&D2=0&D3=0&D4=0&D5=0&D6=l&HD=110926-1748&HDR=T,G1&STB=G2,G5,G3,G4

[56] M. Kintner-Meyer et al., "Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis," Richland, Technical Report 2007.

[57] J.M. Corberan, D.P. Finn, C.M. Montagud, F.T. Murphy, and K.C. Edwards, "A quasi-steady state mathematical model of an integrated ground source heatpump for building space control," *Energy and Buildings*, vol. 43, no. 1, pp. 82-92, January 2011.

[58] International Energy Agency, "Energy Technology Roadmaps: Charting a Low-Carbon Energy Revolution," 2009.

[59] Ángel A. Bayod-Rújula, "Future Development of the Electricity Systems with Distributed Generation," *Energy*, pp. 377-383, 2009.

[60] T.G Werner and R. Remberg, "Technical, Economical and Regulatory Aspects of Virtual Power Plants," in *Procedings of the IEEE Conference 'Electric Utility Deregulation and Restructuring and Power Technologies', DRPT 2008*, Nanjing, 2008, pp. 2427-2433.

[61] Poul H. Andersen, John A. Matthews, and Morten Rask, "Integrating Private Transport into Renewable Energy Policy: The Strategy of Creating Intelligent Recharging Grids for Electric Vehicles," *Energy Policy*, pp. 2481-2486, 2009.

[62] Henrik Lund and Willett Kempton, "Integration of Renewable Energy into the Transport and Electricity Sectors through V2G," *Energy Policy*, pp. 3578-3587, 2008.

[63] Willett Kempton and Jasna Tomic, "Vehicle-to-grid Power Implementation: From Stabilizing the Grid to Supporting Large-Scale Renewable Energy," *Journal of Power Sources*, pp. 280-294, 2005.

[64] C.F.J. Feenstra, "The flexible future of micro combined heat and power: An analysis of the social embedding of micro CHP in Dutch households in 2030," Petten, 2008.

[65] F Kern and A. Smith, "Restructuring energy systems for sustainability? Energy transition policy in the Netherlands," *Energy Policy*, pp. 4093-4103, 2008.

[66] Energienieuws. (2009, February) Nederlander bespaart jaarlijks ongeveer 11 m³ aardgas. [Online]. http://www.gaslicht.com/nieuws/Nederlander-bespaart-jaarlijks-ongeveer-11-m%B3-aardgas.aspx

[67] M.C. van de Lindt and S.B. Emmert, "National report on the Dutch energy regime," 2008.

[68] IEA Heatpump Centre. (2009, April) IEA Heatpump Centre. [Online]. http://www.heatpumpcentre.org/About_heat_pumps/HP_technology.asp

[69] ClimateWell AB. (2009, June) ClimateWell. [Online]. http://www.climatewell.com/Documents/Technical%20Documents/ClimateWell_INSTALLATION_MANUAL_CW20_093_2.pdf

[70] Whisper Tech Ltd. DC Technics Mobile Energy Systems. [Online]. http://www.dctechnics.nl/Downloads/Whispergen/Concept%20Huisinstallatie%20AC.pdf

[71] Nissan. (2010) Nissan Zero Emission. [Online]. http://www.nissan-zeroemission.com/EN/LEAF/specs.html

[72] Vanco Janev, "Implementation and evaluation of a distribution load flow algorithm for networks with distributed generation," Zurich, 2009.

[73] A.D. Hawkes and M.A. Leach, "Cost effective operation strategy for residential micro CHP," *Energy*, pp. 711-723, 2007.

[74] D&H Climate Control. D&H Climate Control. [Online]. http://www.dhclimatecontrol.com/hp.htm

[75] Ibrahim Dinçer and Marc A. Rosen, *Thermal Energy Storage: Systems and Applications*. Chichester: Wiley, 2002.

[76] Viessmann Ltd. Viessmann UK. [Online].

http://www.viessmann.co.uk/downloads/TechnicalSeriesHeatPumps.pdf

[77] Federcasa, "Housing Statistics in the European Union 2005/2006," Rome, 2006.

[78] Jeroen Haringman. (2009) SolarWebsite.nl. [Online]. http://www.solarwebsite.nl/statistieken/statistieken.htm

[79] A.D. Hawkes and M.A. Leach, "The Capacity Credit of Micro-Combined Heat and Power," *Energy Policy*, pp. 1457-1469, 2008.

[80] D Pudjianto, D.M. Cao, S. Grenard, and G. Strbac, "Method for Monetarization of Cost and Benefits of DG Options," Petten, 2006.

[81] SenterNovem. (2011, July) Energie Data. [Online]. http://senternovem.databank.nl/Default.aspx?sel_guid=e0b87083-8cb7-4a67-94e6-ab275d57af81

[82] Agentschap NL. (2011, January) Ministerie van Economische Zaken, Landbouw en Innovatie. [Online]. http://www.agentschapnl.nl/content/samenvatting-evaluatie-epc-aanscherping-woningen-0-8

[83] NEN. (2011) NEN. [Online]. http://www.nen.nl/web/Normshop/Norm/NENEN-134652004-en.htm

[84] H. Schranzhofer, P. Puschnig, A. Heinz, and W. Streicher, "Validation of a TRNSYS simulation model for PCM energy storages and PCM wall construction elements ," in *ECOSTOCK 2006 Conference Proceedings*, New Jersey, 2006.

[85] EC. (2011) European Commission. [Online]. http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

[86] California Energy Commission. (2008, August) California Energy Commission. [Online]. http://www.energy.ca.gov/distgen/

[87] M.G.L.C. Loomans and P.G.S. Rutten (eds.), "Reader Sustainable Thermal Storage Solutions for the Built Environment," Department of Building Physics & Systems, TU/e, Eindhoven, Study material for the course 7S815 2009.

[88] Rijksoverheid. (2010, December) Rijksoverheid. [Online]. http://abonneren.rijksoverheid.nl/media/dirs/436/data/housing_statistics_in_the_european_union_2010.pdf

[89] Gilbert M. Masters, *Renewable and Efficient Electric Power Systems*. Hoboken: Wiley, 2004, LDB 2004 MAS.

[90] Leon Freris and David Infield, *Renewable Energy in Power Systems*. Chippenham: Wiley, 2008, LDB 2008 FRE.

[91] City and County of Swansea. (September, 2009) City and County of Swansea. [Online]. http://www.swansea.gov.uk/index.cfm?articleid=25452

List of Figures and Tables

List of Figures

List of Tables

Part IV

Appendices

Appendix A
Housing Characteristics

The most common types of housing are typified in the *Referentiewoningen Nieuwbouw* report prepared by SenterNovem for the VROM Ministry in 2006 [40]. This report is intended as a theoretical basis to aid in the planning process of new buildings in accordance with the building code targets and regulations effective at the time.

The types of dwellings referenced in the report are terraced, corner, semi-detached and detached houses, gallery complexes and apartments. From these six, only four will be used for calculations in this project. This is for simplification purposes, given that two pairs of housing types (terraced and corner houses, and apartments and gallery houses) are very similar to each other.

This appendix discusses the basic characteristics of these four reference dwellings and their typical energy use for space heating and DHW. All figures in these sections were obtained from [40] and [8].

A.1 Terraced Houses

Also known as row houses, terraced dwellings are identical or mirror-image houses with shared side walls laid out in a single line. The first and last of these are called a corner house, and may or may not be larger than the houses in the middle. This type of dwelling comprises 47% total building stock in the Netherlands as of 2008, and has approximately the same share in new constructions. An average terraced house has two floors 2.6 m high and an attic with a roof with height 4.9 m. Its floor area is 124.3 m², and consumes approximately 99.7 kWh/m²/a for space heating and domestic hot water. Assuming a more or less steady annual use of 23.3 kWh/m² for DHW[13], the total energy demand for space heating is **76.4 kWh/m²** per year.

A.2 Semi-Detached Houses

Built side by side with a shared wall, semi-detached houses are laid out in pairs as mirror images of each other. This type of dwelling makes up 14% of the total building stock in the Netherlands, and has around the same share in the total amount of new buildings constructed. Its average floor area is 147.7 m². The annual space heating demand amounts to **88.1 kWh/m²**. This figure plus DHW heating requirements gives a total demand of 111.4 kWh/m²/a.

[13] According to data from the SenterNovem Energy Statistics Database [8], and trends from the National report on the Dutch Energy Regime [63]. This figure of 23.3 kWh/m²/a will be used for the other three reference dwellings as well.

Figure 36 - Floor and elevated plans of a terraced house [40]

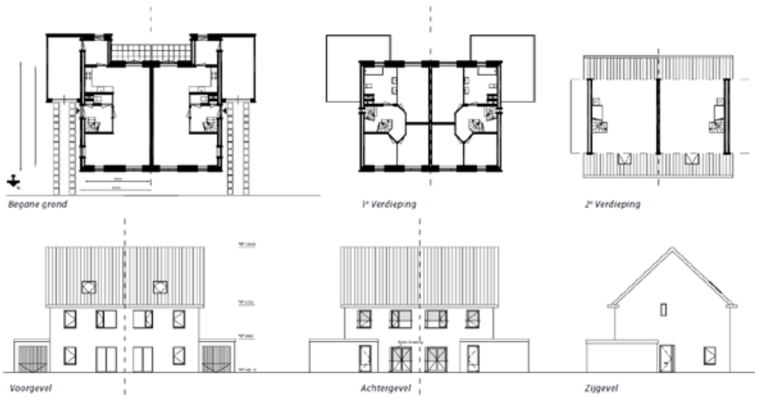


Figure 37 - Floor and elevation plans of a semi-detached house [40]

A.3 Detached Houses

Detached, or free-standing houses, are single-family homes that do not have any inside walls in common with another house or dwelling. Accounting for approximately 11% of the current building stock in the Netherlands, construction of this type of housing has slowed down in the past years due to an increase in population density and urbanization. Currently, detached houses only make up 5% of the new building stock in the Netherlands. The average floor area of these dwellings is 169.2 m², and their space heating demand amounts to **92.5 kWh/m²** for a total of 115.8 kWh/m²/a including DHW.

Figure 38 - Floor and elevation plans of a detached house [40]

A.4 Apartments

Apartments, also known as flats, are self-contained housing units within a building. Currently making up around 27% of the current building stock in the Netherlands, factors such as urbanization and increased population density have boosted new constructions of this type of dwelling. As of 2006, they represent 33% of the new building stock in the Netherlands. On average, their usable floor area is 81.7 m², and their annual space heating demand amounts to **73.5 kWh/m²**, totaling 96.8 kWh/m² inclusive DHW.

Figure 39 - Floor and elevation plans of an apartment complex [40]

Appendix B
Building Performance Simulations, Base Case

Building performance simulations of the reference buildings are necessary to establish a base case on which to apply and quantify the energy saving measures of the passive design outlined in Sections 3.1 and 5.1. Input parameters for the base case are taken from tabulated values and floor and elevation plans from the *Referentiewoningen Nieuwbouw* report referenced in Appendix A, unless otherwise specified. The simulations were carried out using the University of Siegen's educational software CASAnova.

B.1 Method of Calculation

CASAnova uses a one-zone model for its calculations, in which it is assumed that the room air and the confining walls of the rooms have a uniform temperature, and temperature changes obey the ordinary differential equation:

$$C \cdot \frac{dT}{dt} = \dot{Q} \quad (4)$$

Where $\dot{Q}$ is the rate of change of the difference between heat gains and heat losses in the system and C the building's thermal capacitance. T is solved for iteratively in one-hour intervals. If the room air temperature falls outside the set thermal comfort limits, the amount of cooling or heating energy needed to adjust the room temperature to the upper or lower temperature bound is calculated, and the room air temperature is reset to the upper or lower bound before the next time interval.

B.2 Simulation Inputs

B.2.1 Climate

Monthly average outside temperature values for the Hoogeveen meteorological station from KNMI, for the years 2008-2010, are shown in Figure 40:

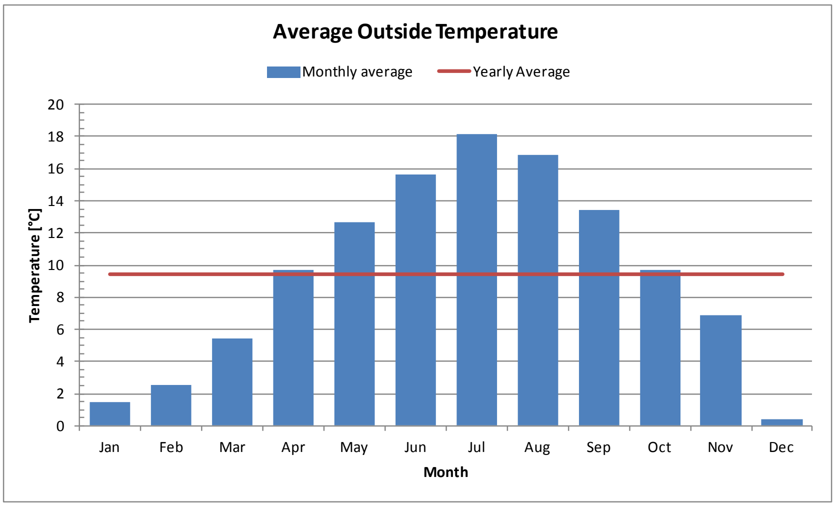


Figure 40 - Average monthly outside temperature, Hoogeveen meteorological station

B.2.2 Geometry

B.2.2.1. Terraced House

The terraced house is modeled in CASAnova as a two-storey house with an attic and shared eastern and western walls. The house is oriented due south, and its roof ridge is aligned on east-west direction. The dwelling's footprint is 57.8 m² (5.9 m × 9.8 m). Each storey is 2.9 m high and the roof is 4.9 m tall. The total usable floor area and air volume are 124.6 m² and 372.4 m³ respectively.

B.2.2.2. Semi-Detached House

The semi-detached house is modeled as a two-storey house with an attic and a shared eastern wall. The house is also oriented due south and the roof ridge is east-west aligned. Its footprint is 68.5m² (6.4m × 10.7 m). Each storey is 2.85 m high, and the attic has a height of 4.9m. The house has a usable floor area of 147.6m² and an air volume of 446.5m³.

B.2.2.3. Detached House

Also a two-storey house with an attic and a due-south orientation, this dwelling has no shared walls and its roof ridge is aligned north--south. Its footprint is 80.9m² (7.7m × 10.5 m). Each storey is 2.85 m high, and the attic has a height of 3.9m. It has a usable floor area of 169.2m² and an air volume of 494.8m³.

B.2.2.4. Apartment

The apartment is modeled as a 1 storey-dwelling with a due-south orientation and east and west shared walls. It has a ground area of 102.1m² (8.3m × 12.3m) and a usable floor area of 81.7m². The ceiling is 2.6m high. The total air volume of the dwelling is 212.3m³.

The geometrical schematics of all four dwellings are depicted in Figure 41 below:

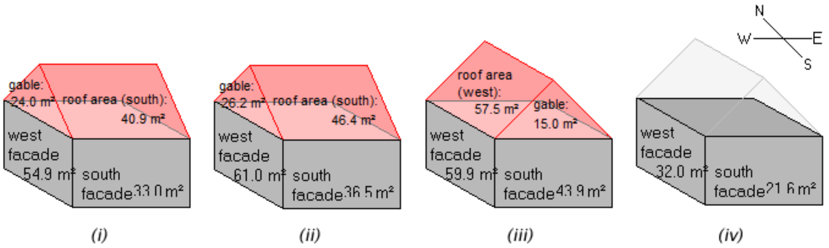


Figure 41 - Geometrical modeling of the reference dwellings in CASAnova: (i) terraced, (ii) semi-detached (iii) detached, (iv) apartment

B.2.3 Fenestration

The windows in all of the reference buildings are heat-protection double glazing with a U-value of 1.80 W/(m²K) and a solar heat gain coefficient (SHGC or g-value) of 0.6.

As per software default values, window areas are designated as 5% of the wall area for the north, east and west façades, where applicable, and 40% for the south façade. The window frames, with U-value 2.00 W/(m²K), are set by default to make up 20% of the total window area. The window assemblies have a shading factor of 20%.

Table 19-Table 22 describe the input values used in CASAnova for the different types of dwellings.

Table 19 - Fenestration characteristics of a reference terraced house

Windows	Fraction of wall [%]	Window area [m²]
N	5	1.7
S	40	13.2
Total area [m²]		14.9
Glazing area [m²]		11.9

Table 20 - Fenestration characteristics of a reference semi-detached house

Windows	Fraction of wall [%]	Window area [m²]
N	5	1.8
S	40	14.6
W	5	3.0
Total area [m²]		19.5
Glazing area [m²]		15.6

Table 21 - Fenestration characteristics of a reference detached house

Windows	Fraction of wall [%]	Window area [m²]
N	5	2.2
S	40	17.6
E	5	3.0
W	5	3.0
Total area [m²]		25.7
Glazing area [m²]		20.6

Table 22 - Fenestration characteristics of a reference apartment

Windows	Fraction of wall [%]	Window area [m²]
N	5	1.1
S	40	8.6
Total area [m²]		9.7
Glazing area [m²]		7.8

B.2.4 Insulation

The walls and floor of the terraced, semi-detached and detached dwellings have an overall heat transfer coefficient of 0.33 W/(m²K), while the U-value for the roof is 0.25W/(m²K). In the case of the apartment, U-values for the walls and floor are set at 0.25 W/(m²K), and 0.2 W/(m²K) for the roof.

Shared walls in the terraced, semi-detached and apartment models are assumed by the software to have an adiabatic behavior, as no heat transfer occurs due to transmission or solar gains.

The effect of heat bridges at junctions in all four models have been accounted for, and are simulated in CASAnova by increasing U-values of surrounding planes by 0.10 W/(m²K).

The front door, in all instances, has an area of 1.9m² and a U-value of 2.0 W/(m²K). By program defaults, it is located in the northern façade.

B.2.5 Building Envelope Heating and Cooling Loads

To estimate the annual energy needed for a building's space heating and cooling, it is necessary to know the following [19]:

- The building's internal solar gain rate;
- heat-loss rate (envelope and infiltration);
- balance point temperature;
- the time periods during which the outside temperature is less than the building's balance point temperature (heating degree days);
- the time periods during which the outside temperature is more than the building's overheating point temperature (cooling degree days);

Passive solar gains are calculated automatically by CASAnova from the hourly direct and diffuse irradiance values in the climate data file, and the heat transfer coefficients of the different assemblies of the building envelope; e.g., walls, roof, floor, and windows. The heating degree days are calculated from the hourly temperature values found in the climate data file and the balance point temperatures set by the user.

B.2.5.1. **Thermal Comfort**

The set point for indoor temperature during winter is 20.0°C, and the overheating limit during the summertime is set at 26.0°C.

B.2.5.2. **Thermal Mass**

CASAnova distinguishes among three types of construction: lightweight, medium and heavy. These are characterized by their thermal capacity per square meter wall area. By program defaults, the building's exterior and interior envelopes are assumed to be of medium construction with a characteristic thermal capacity of 65 kJ/(m² K).

B.2.5.3. **Internal Gains**

The total cooling load during the summer period is estimated from the combination of the passive solar gains and internal gains of the building. A simplified internal heat gain procedure for residential buildings typically includes gains from artificial lighting, building population, and appliances [19]. The values obtained in this section apply for all types of dwellings.

People
In residential buildings, sensible heat gain per occupant is often assumed at 67.3 W. From CBS statistical data, the average Dutch household has about 2.3 occupants [49]; this yields a heat gain of 154.8 W.

Lighting

For residences, sensible heat gain from lighting can range from 2.2 to 21.5 W/m² of floor area, depending on the daylight factor (DF). Empirically, the average daylight factor can be approximated with equation (5) [19]:

$$DF_{av} = 0.2 \frac{\text{window or skylight area}}{\text{floor area}} \times 100\% \quad (5)$$

The average daylight factors for the reference buildings are shown in Table 23 below:

Table 23 - Average daylight factors for each building type

	Terraced	Semi-detached	Detached	Apartment
DF_{av} [%]	1.9	2.1	2.4	1.9

These average daylight factors are then used to look up the sensible heat gains from lighting from Table F.3 in [19]. For $1 \leq DF \leq 4$, recommended sensible heat gains range from 2.2 to 8.5 W/m² floor area. For the simulations, the average value of 5.35 W/m² was used.

Appliances

The standard practice is that 350-470 W of sensible heat gain is produced by electrical/electronic equipment. Other residential heat loads are assumed to be vented [19]. A worst-case scenario of 470W equipment heat gain will be used for the cooling load calculations.

The total internal gains for each type of dwelling are obtained by adding the gains of building population, lighting and equipment, and dividing by the floor area.

Total internal gains for each type of building are shown in Table 24:

Table 24 - Specific internal gains per type of building

	Terraced	Semi-detached	Detached	Apartment
People [W]	154.8	154.8	154.8	154.8
Appliances [W]	470.0	470.0	470.0	470.0
Lighting [W]	666.1	789.7	905.2	437.1
Total gains [W]	1290.9	1414.5	1530.0	1061.9
Total specific gains [W/m²]	10.4	9.6	9.0	13.0

B.2.6 Ventilation

B.2.6.1. Mechanical Ventilation

Mechanical ventilation is defined as the deliberate, designed introduction of outdoor air in order to ensure indoor air quality of the building [19]. In SI units, airflow rates can be expressed in [l/s] or air changes per hour (ACH) [1/h].

The SenterNovem report mentions the presence of a mechanical ventilation system with no heat recovery system in the reference buildings, but fails to specify the airflow rate of the equipment. In order to quantify the airflow rates of the mechanical ventilation system, reference to norms such as the European standard NEN-En 13465:2004 or the 2009 ASHRAE Fundamentals Handbook , must be made. These standards specify basic calculation methods to determine whole-house airflow rates for single family houses and individual apartments.

According to the 2009 ASHRAE Fundamentals Handbook, the total ventilation air requirements for a residential building are 0.15 l/s per square meter of floor space plus 3.5 l/s per person, based on normal occupancy [18]. The method of calculation is shown in Equation (6):

$$\text{ACH} = \frac{\left(0.15\frac{l}{s}\frac{1}{m^2}(\text{floor space}) + 3.5\frac{l}{s}\frac{1}{\text{person}}(\#\text{people})\right)\frac{1m^3}{1000l}\frac{3600s}{1h}}{\text{building air volume}} \quad [h^{-1}] \qquad (6)$$

The total ventilation air requirements for each type of dwelling are summarized in Table 25 below:

Table 25 - Mechanical ventilation air requirements per type of building

	Terraced	Semi-detached	Detached	Apartment
ACH [h^{-1}]	0.27	0.25	0.24	0.35

B.2.6.2. Infiltration

Infiltration is the unintended influx of outdoor air due to air leakage through the building skin [19]. The infiltration rate of the building envelope was estimated from Table E.27 of [19], which lists estimated values of ACH as a function of construction type related to air-tightness and climate [19].

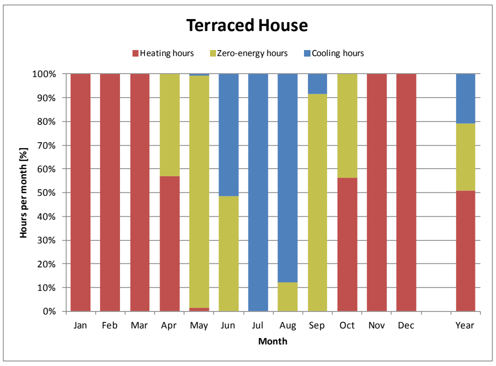
The building is assumed to be a tight construction; i.e., that it has well-fitted windows and weather-stripped doors. The winter outdoor design temperature was set to the minimum monthly mean temperature value from the Hoogeveen weather station (0.40°C) [42]. Interpolating the data, the infiltration rate is found to be approximately 0.45 h^{-1}. This value holds for all four types of dwellings.

B.2.7 Terminal Systems

The heat exchanger for the space heating system consists of a high efficiency boiler (HR-107) running on natural gas. The heat is delivered throughout the home by means of a high-temperature (70/55°C) radiator distribution system. None of the houses have been fitted with air conditioning units for the cooling season.

B.3 Simulation Results

The energy performance of each type of house in terms of heating, cooling and neutral-energy hours is depicted in Figure 42:



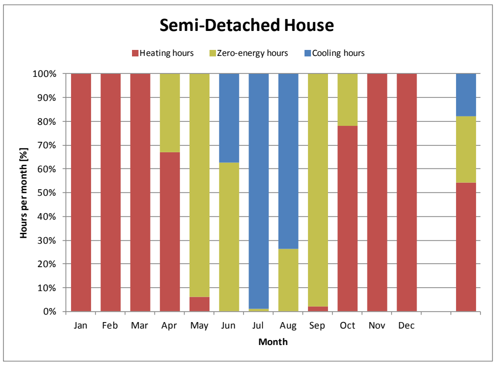


Figure 42 - Building performance for the reference houses in terms of energy hours

The monthly heating demands per type of house are graphed in Figure 43 below:

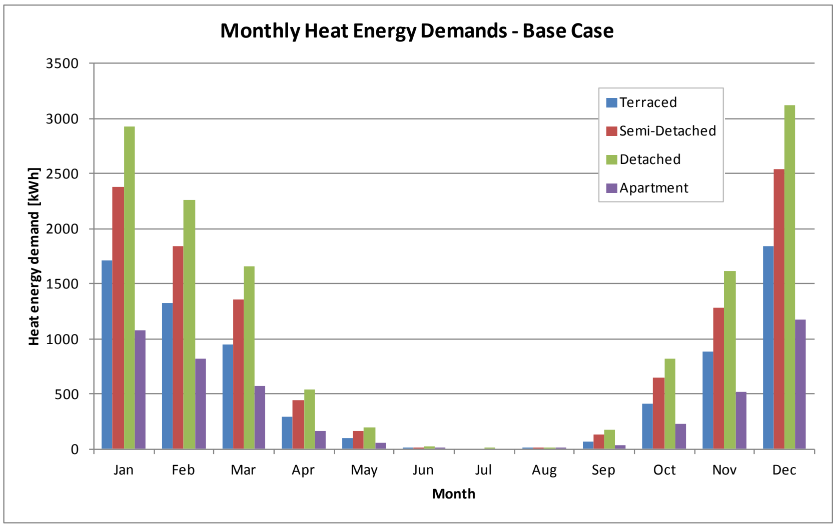


Figure 43 - Monthly heat energy demands, base case

Table 26 gives the simulation results of the primary energy requirements for space heating for the reference buildings, and compares them to the energy usage values from the *Referentiewoningen Nieuwbouw* report.

Table 26 - Primary energy requirements comparison between CASAnova model and SenterNovem values

Type of house	Primary energy demand for space heating [kWh/(m²a)]		Error [%]
	SenterNovem report	CASAnova model	
Terraced	76.4	76.8	0.5
Semi-detached	88.1	88.6	0.6
Detached	92.5	94.1	1.7
Apartment	73.5	73.7	0.3

It can be seen from the table that the CASAnova models are indeed a very good approximation of the SenterNovem reference buildings, and thus are a valid basis for studying the effects of implementing the energy saving measures discussed in Chapter 3 and Chapter 5, and as simulated in Chapter 6.

Appendix C
Active solar systems

C.1 Irradiance Data

Irradiance values for Steenwijk are taken from the Hoogeveen meteorological station, and amounted to a yearly insolation of 1041.6 kWh/m² in 2009 [42]. Values for irradiance incident on a horizontal surface during an average winter and summer days are shown in Figure 44:

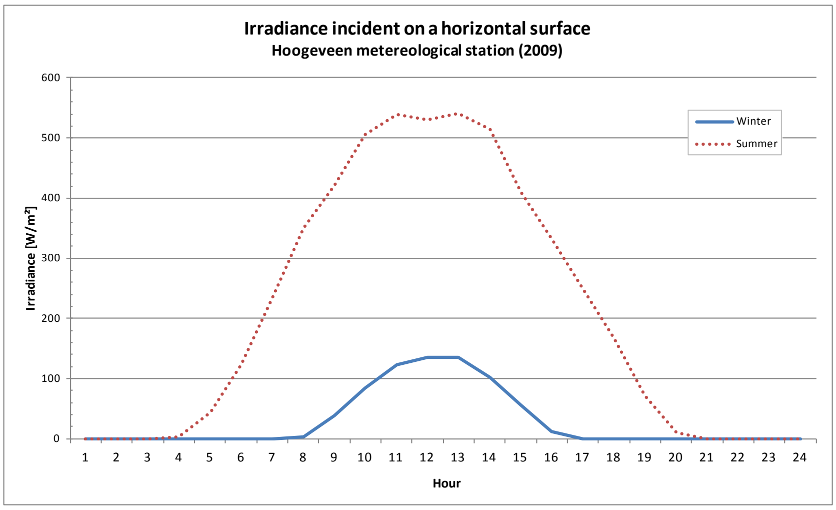


Figure 44 - Daily Irradiance incident on a horizontal surface, Hoogeveen 2009

C.2 PV system

C.2.1 PV Specific Annual Yield

A commercial 1 kWp PV module composed of polycrystalline solar cells is assumed for the household installation. Such a module would have a theoretical specific annual yield of 1041.6 kWh/kWp under STC[14] on a horizontal surface. However, the modules are subjected to conditions different from STC, and are also tilted at an angle in order to maximize power output. Therefore, it is necessary to introduce empirical correction factors that take these conditions into account. Using guidelines from the German Society of Solar Energy, the ideal yield needs to be multiplied by a tilt correction factor of 1.21,

[14] Standard Test Conditions: A set of reference photovoltaic device measurement conditions consisting of irradiance of 1 kW/m², solar spectrum of AM 1.5, and module temperature of 25 °C.

and an STC temperature-deviation factor of 0.94 [24]. This leads to a new specific annual yield of 1184.7 kWh/KWp, assuming no energy conversion losses in the system.

Taking the energy conversion losses detailed in Table 27, the real specific annual yield of a 1 kWp module in Steenwijk is expected at 924.1 kWh/kWp.

Table 27- Energy conversion losses of the PV system

Other STC-deviations	4.5%
Soiling	2.5%
Temperature	3.5%
Shading	2.0%
Mismatching & DC	3.5%
MPP mismatch	1.5%
Inverter	4.0%
AC conversion & meter	3.0%
System conversion efficiency	**78.0%**

C.2.2 Electricity Production

Taking a typical module efficiency of 15% for polycrystalline silicon solar cells, and the adjusted yearly sum of irradiance from the previous section, the total electricity production of the system would be 138.6 kWh/m²/a.

This means that a total installed capacity of 2.0 MWp would be required to satisfy the electricity demand of De Schans by 2030. The installed capacity and area requirements for the modules are broken down in Table 28 per type of dwelling:

Table 28 - PV installed capacity and surface area requirements per type of house

Type of house	Installed capacity [KWp]	Area req. [m²]
Terraced	4.7	31.4
Semi-detached	5.6	37.3
Detached	6.4	42.8
Apartment	3.1	20.6

C.3 Solar thermal DHW system

Table 29 shows average irradiance values for an average day in each month, taking into account the optimized tilt correction factor from the previous section:

Table 29 - Average irradiance incident on an optimally tilted surface

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	4	11	4	0	0	0	0	0	2
5	0	0	0	5	57	73	53	13	0	0	0	0	17
6	0	0	4	59	170	199	149	83	20	0	0	0	57
7	0	1	48	176	313	325	280	210	106	26	0	0	124
8	4	27	128	322	463	425	420	334	242	98	17	1	208
9	45	88	198	453	605	564	505	446	340	198	61	32	296
10	102	146	276	596	682	657	606	572	413	251	98	81	374
11	148	174	325	669	684	712	646	645	434	303	126	123	417
12	163	183	348	698	700	652	637	667	438	295	136	140	423
13	162	153	332	678	670	630	649	661	472	279	116	123	412
14	122	134	291	593	612	670	618	575	416	244	84	79	371
15	68	98	232	479	516	550	493	481	345	167	46	29	293
16	15	46	166	337	372	443	399	383	223	70	6	0	206
17	0	8	92	216	276	321	298	246	97	10	0	0	131
18	0	0	16	84	164	207	201	121	19	0	0	0	68
19	0	0	0	7	57	100	86	23	0	0	0	0	23
20	0	0	0	0	4	18	13	0	0	0	0	0	3
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0
Total insolation [Wh/m²/d]	**828**	**1058**	**2456**	**5372**	**6349**	**6558**	**6058**	**5459**	**3566**	**1942**	**692**	**608**	**3425**

The average insolation in the summer months (May-Aug) is to 6.1 kWh/m².

From the calculations in Section 5.3.2, the required collector area for this application is 3.6 m². The expected solar contribution to the DHW system, per month, based on this collector area, is tabulated below:

Table 30 - Expected solar thermal contribution to the DHW system (%)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
14%	17%	40%	88%	100%	100%	99%	89%	58%	32%	11%	10%	56%

Appendix D
Network Design

D.1 Strand-Axelsson loads

The load profile of a typical consumer type (e.g. residential, commercial or industrial) represents the average behavior, or demand characteristics of their consumption, and is therefore very useful for network planners for defining the capacity requirements for equipment in terms of system peak load [45].

The correlation between system peak load and energy demand is heavily dependent on the load pattern, the number of customers connected to the network, and the degree of simultaneity/coincidence of their energy use. Extensive load curve data need to be collected and analyzed before a suitable mathematical approximation of this behavior can be modeled and used for forecasting the peak loads of other similar networks.

The most widely used method in the Dutch power industry for translating annual energy demands into peak demands per customer is the Strand-Axelsson formula [50]. Assuming a large, homogeneous group of consumers, symmetric loads, and a radial network operation, the coincident peak load for n customers is given by:

$$P_{max}(n) = \alpha \cdot E_1 + \beta \cdot \sqrt{\frac{E_1}{n}} \tag{7}$$

Where P_{max} is the maximum load, E_1 the yearly energy demand of a single consumer, and α and β are empirical coefficients inherent to a given load pattern.

Values for α and β for the different types of houses are taken from NV RENDO, and are tabulated below:

Table 31 - Empirical coefficients for Strand-Axelsson calculations

Type of dwelling	$\boldsymbol{\alpha}\ (\times\ \mathbf{10^{-3}})$	$\boldsymbol{\beta}$
Terraced	0.268	0.0239
Semi-detached	0.268	0.0239
Detached	0.305	0.035
Apartment	0.237	0.0444

For $\mathrm{n} = 1$, the maximum load per type of house is given in Table 32:

Table 32 - Expected maximum load [kW], Strand-Axelsson calculations ($n = 1$)

Type of dwelling	$\boldsymbol{P_{max}}$ **[kW]**
Terraced	2.47
Semi-detached	2.79
Detached	4.06
Apartment	2.79

D.2 Discarded LV network designs

The following subsections briefly describe the iterative design process of the final network proposed in this thesis project. The grid design was based upon guidelines found in literature, such as the handbook *Elektriciteitsdistributienetten*, by EnergieNed [50], and reference books from Willis [45] and Lakervi [51]. Additionally, grid design, especially in the second iteration and final design, heavily relied on the practical expertise and experience of the engineers at NV RENDO.

The first proposed layout is depicted in Figure 45(i) below. In the figure, red and green placemarks denote existing MV/LV substations; the yellow placemarks indicate the location of the new transformer substations, and the cyan lines are the feeders that make up the mesh-shaped distribution network.

(i) *(ii)*

Figure 45 - Discarded LV network designs for De Schans

The main problem with this design was that, because the transformer stations are far apart from some of the loads and from each other, there are many cables in the system that are more than 350m long, which increases potential problems related to voltage drop.

The second iteration of the design included adding a third transformer station and relocating the second one for a better distribution of the loads. This can be found in Figure 45(ii). The design uses the three new distribution stations (yellow placemarks) plus three of the nearby surrounding stations (green and red placemarks).

The main problems with this design were:

- The loads connected to the existing distribution stations were too far away to offset/justify the costs of installing the conductors.
- Instead of using two cables per street (95Al), it would be better for a single, greater caliber conductor (150Al) to supply the loads on both sides of the street.
- The section boxes at the end nodes are practical for the radial operation of the meshed network, but their locations are very close to the houses. That could be a problem for maintenance and operation, as the neighbors might not like this idea.
- As seen in Section 5.4.1, meshed networks rarely offer a competitive advantage or added value over well-designed radial networks at LV, so the mesh design of this iteration is most likely not worth the added investment costs in infrastructure and operation

Appendix E
Load Profiles

E.1 Loads at the secondary of the transformer

The following electricity demand profiles are estimates for the year 2030 for De Schans. They were obtained by scaling the loads from the Calkoenstraat distribution station used in Section 5.1.2 with the number and types of houses corresponding to the new development *(see next section for tabulated values)*.

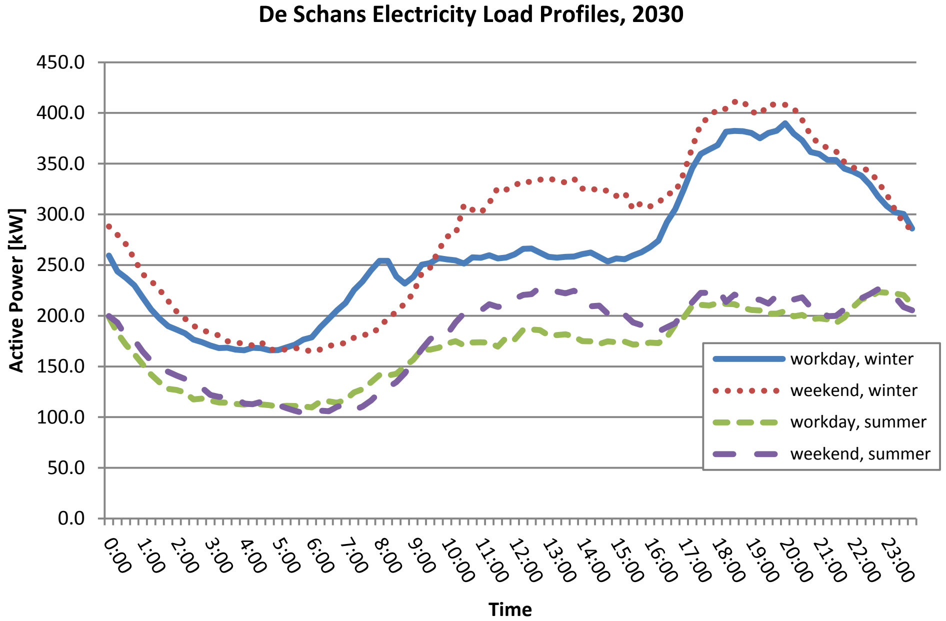


Figure 46 - De Schans 2030 load profiles

Figure 46 illustrates the peaks and fluctuations in demand on the secondary side of the transformer at an aggregate level, and is built upon the assumption that the 400 houses are supplied with electricity by only one transformer station. Given that industry common practice dictates that one MV/LV distribution station service no more than 300 houses, the housing development requires supply from at least two distribution stations. Detailed information on the proposed LV network design can be found in Section 5.4.

E.1.1 Method of calculation

The total demand in 2030 in De Schans sums 1841 MWh/a. Assuming that the load pattern from the De Schans housing complex is analogous to that of the existing Calkoenstraat distribution station referenced in Section 5.1.2, a scaling factor is defined by the ratio of the annual demands for De Schans in 2030 and the registered annual demand for Calkoenstraat in 2009:

$$\text{Scaling factor} = \frac{\text{Annual demand, De Schans 2030}}{\text{Annual demand, Calkoenstraat 2009}} = \frac{1841\ MWh/a}{996\ MWh/a} = 1.85\ [-] \qquad (8)$$

Multiplying each 15-minute loads by the scaling factor gives the average workday and weekend load profiles for the coldest and warmest months of the year (January and July, respectively), shown in Table 33.

Table 33 - 2030 expected workday and weekend loads, De Schans

Time	Active power [kW]				Time	Active power [kW]			
	Winter loads		Summer loads			Winter loads		Summer loads	
	workdays	weekends	workdays	weekends		workdays	weekends	workdays	weekends
0:00	259.3	288.0	198.6	199.8	12:00	260.7	328.6	176.7	216.8
0:15	243.7	279.8	183.1	193.2	12:15	265.9	332.8	186.2	220.5
0:30	237.4	270.6	171.4	179.6	12:30	266.3	331.7	186.5	221.4
0:45	230.0	256.1	162.1	176.2	12:45	262.2	334.1	185.8	228.1
1:00	218.0	241.1	152.0	164.7	13:00	258.2	335.7	180.7	226.0
1:15	206.2	234.2	142.0	155.4	13:15	257.3	333.0	180.9	223.9
1:30	197.3	225.6	134.3	150.1	13:30	258.1	331.4	181.7	222.1
1:45	189.8	214.8	127.9	144.8	13:45	258.4	335.3	179.5	224.7
2:00	186.4	204.2	126.8	141.0	14:00	260.7	325.3	174.9	220.3
2:15	182.7	197.1	124.3	137.6	14:15	262.4	326.3	174.7	209.4
2:30	176.6	190.2	117.4	131.4	14:30	258.0	322.6	172.1	210.0
2:45	174.0	186.4	118.2	129.2	14:45	253.5	323.7	174.8	202.2
3:00	170.7	182.8	116.5	121.9	15:00	256.5	318.2	173.8	195.7
3:15	168.2	180.6	114.5	120.1	15:15	255.7	321.5	174.5	201.1
3:30	168.5	175.0	114.4	120.0	15:30	259.5	304.8	171.6	193.4
3:45	166.5	173.2	113.1	119.3	15:45	262.7	311.5	171.9	190.7
4:00	166.0	172.8	112.5	113.3	16:00	267.6	307.9	173.6	184.8
4:15	168.4	170.6	113.6	112.8	16:15	274.1	311.2	173.1	184.4
4:30	168.0	174.0	112.6	115.2	16:30	292.3	320.3	178.9	188.7
4:45	166.0	166.7	111.9	112.2	16:45	305.1	321.5	191.2	192.7
5:00	166.2	166.1	110.3	111.9	17:00	324.6	340.6	198.4	204.1
5:15	168.8	166.9	111.2	109.0	17:15	345.6	365.8	209.8	213.3
5:30	171.5	168.1	111.0	106.2	17:30	359.5	389.3	210.8	222.6
5:45	176.6	167.2	110.6	104.1	17:45	364.1	396.0	210.1	222.7
6:00	178.7	164.4	109.6	103.3	18:00	368.2	404.0	212.4	226.7
6:15	188.6	166.8	115.5	106.5	18:15	381.5	404.1	211.7	213.6
6:30	197.0	170.4	115.6	105.8	18:30	382.4	410.9	211.5	220.9
6:45	205.4	171.4	114.1	110.2	18:45	381.9	411.9	207.8	217.4
7:00	212.7	173.4	117.2	112.5	19:00	380.2	401.5	205.7	216.2
7:15	225.4	178.4	124.4	106.9	19:15	375.0	398.4	205.2	215.9
7:30	233.8	181.1	127.5	110.6	19:30	380.3	408.3	202.1	212.0
7:45	244.9	181.7	134.3	116.4	19:45	382.4	408.2	202.0	219.8
8:00	254.2	188.5	141.7	124.6	20:00	389.9	408.0	204.6	221.5
8:15	254.1	197.7	141.0	129.2	20:15	379.6	404.8	199.4	216.0
8:30	238.7	203.8	142.7	134.5	20:30	373.0	393.3	200.8	218.2
8:45	231.8	212.2	150.1	143.2	20:45	361.4	378.0	196.4	208.5
9:00	238.2	222.3	156.6	155.7	21:00	359.5	369.1	197.5	208.9
9:15	250.4	241.9	166.8	167.0	21:15	353.8	365.8	196.3	199.5
9:30	251.9	247.3	166.5	176.8	21:30	353.6	362.2	192.9	200.0
9:45	256.9	264.6	168.5	182.7	21:45	345.0	351.6	198.3	206.6
10:00	255.5	278.1	172.5	181.5	22:00	342.2	346.0	208.4	212.1
10:15	254.7	280.3	175.0	193.5	22:15	338.1	345.6	216.1	217.3
10:30	251.5	309.6	170.9	202.5	22:30	329.4	343.1	218.6	221.4
10:45	257.7	304.5	173.6	205.3	22:45	317.6	331.6	223.4	226.2
11:00	257.1	301.5	173.9	205.1	23:00	308.4	319.8	222.8	222.6
11:15	259.7	311.3	173.5	211.3	23:15	302.0	304.1	222.0	218.3
11:30	256.6	326.3	169.6	208.8	23:30	300.5	291.3	220.4	208.6
11:45	257.5	324.3	178.4	210.0	23:45	286.1	284.5	210.9	205.4

Total demands per type of household for the entire De Schans housing complex by the year 2030 are shown in Table 34 below.

Table 34 - De Schans electricity demands, 2030

	Terraced	Semi-detached	Detached	Apartments
Demand per house, per type [kWh/a]	4351	5171	5934	2860
Number of houses	153	90	85	72
Total demand per type [MWh/a]	**666**	**465**	**504**	**206**

E.2 Special loads

E.2.1 Plug-in electric vehicles (PEV)

Load patterns for the charging of PEVs were adapted from the work of Gerkensmeyer, et al, [52] and DeForest, et al [53], to Dutch driving patterns for privately owned vehicles.

In 2009, the total passenger fleet in the Netherlands was 7.5 million cars [54]. With a little over 7.3 million private households in the Netherlands, there are approximately 1.03 cars per household. The average mileage on these vehicles was 13500 km/a in 2009, or 37.3 km per day [55].

The per-vehicle load is assumed to be 3.3 kW for the duration necessary to fill the battery, as per [53].The duration of the load —i.e., the time needed for the EV battery to recharge— is a function of the daily driving pattern, the EV consumption rate, and the charging circuit efficiency, and is given by:

$$\text{Load duration } [h] = \frac{\text{EV consumption } [kWh/km] \times \text{driving distance } [km]}{\text{EV load } [kW] \times \eta_{\text{charging circuit}} \; [-]} \qquad (9)$$

For this case, an average consumption rate of 0.22 kWh/km is taken from a PNNL-DoE report [56], and the battery charging circuit efficiency is assumed to be 87% [52]. The load duration is calculated at 3 hours.

Two charging scenarios are posited: one where the EVs will be charged after people arrive home from work, and one where the EVs will be charged before people go to sleep, after the peak period has passed. These charging times are modeled as normal probability distribution functions with the following parameters:

- Charging after work: mean: 18.00h, standard deviation: 30 minutes.
- Charging before going to sleep: mean: 23.00h standard deviation: 30 minutes.

The resulting EV load profiles, in p.u. are shown in Figure 47.

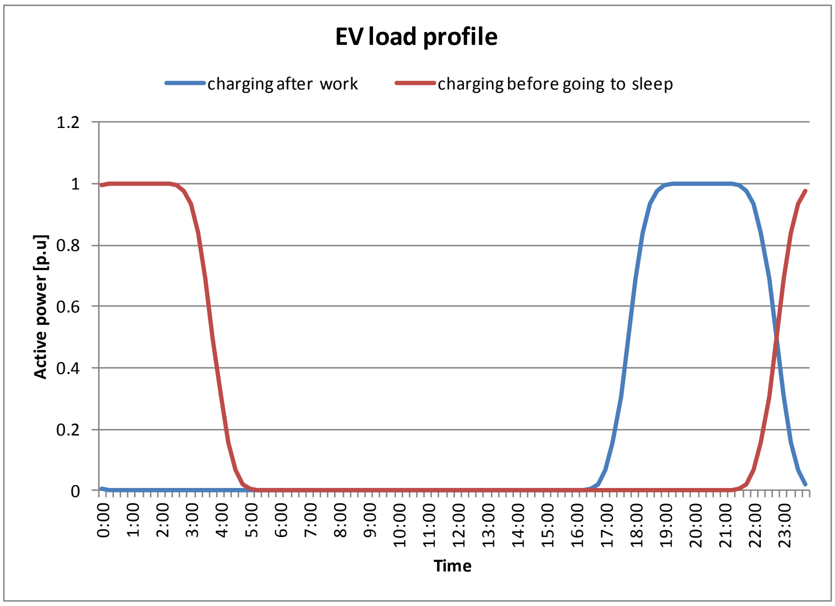


Figure 47 - EV load profiles

E.2.2 Heat pumps

The load profile for the geothermal heat pump was adapted from Corberan, et al [57], and is depicted in Figure 48.

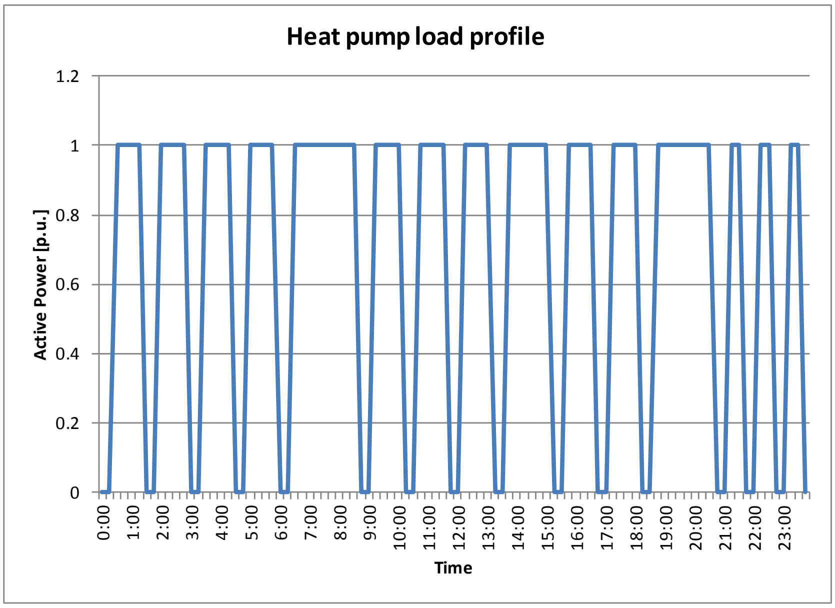
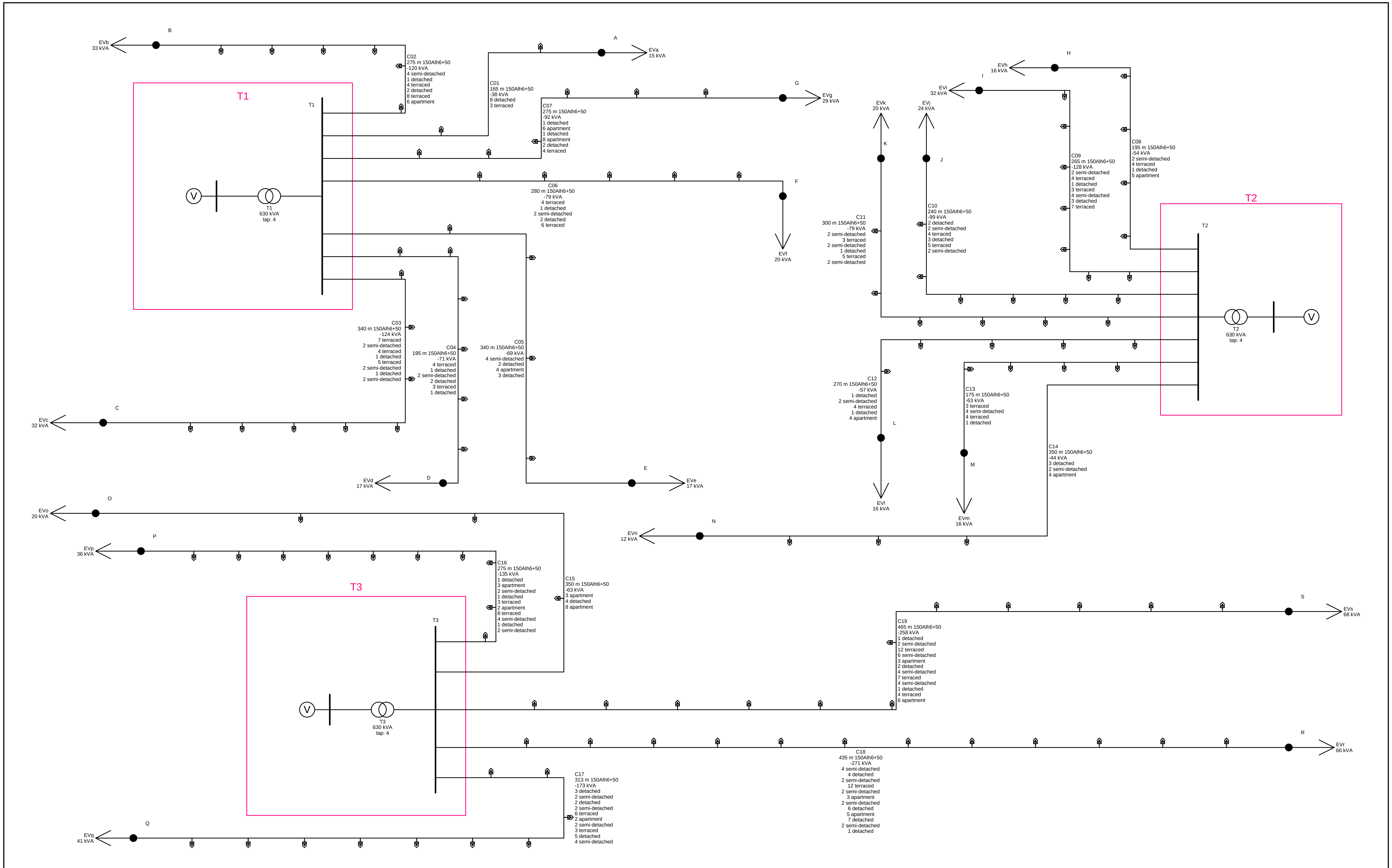


Figure 48 - Geothermal heat pump load profile (adapted from [57])



TU/e Technische Universiteit Eindhoven University of Technology

RENDO NETWERKEN

PHASE TO PHASE

Project: Steenwijk—De Schans
Elaborated by: R.M.D.G. Morales González
Program: Gaia 6.2
Date: September 2011