MASTER

Reducing power peaks from renewable energy sources on the grid connection

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Nomenclature

ACH:	Air changes per hour
COP:	Coefficient of performance
CV-RMSE:	Coefficient of variation – root mean square error
DH:	District heating
MBE:	Mean bias error
OEF:	On-site energy fraction
OEM:	On-site energy matching
RES:	Renewable energy sources
SES:	Smart energy system
SOC:	State of charge

Abstract

Electric energy produced by renewable energy sources, like wind power, have an intermittent production. During times of high electricity production not all the electricity might be consumed by the buildings demand. This surplus electricity from the generation introduce stress to the district grid, the transformer needs redeliver the electricity back to the public grid. To handle these peaks the grid infrastructure requires investments. Therefore, lowering the peaks could potentially reduce these investments. This could be achieved by storing the peak power on the district side before it is injected into the public grid.

In this paper, a case study is presented to evaluate the possibility of storing energy inside a business park to lower the power peak on the grid connection. The power on the grid connection is the power generated on-site minus the power demand from the buildings. Power peaks exceeding 1 MW need are stored on site. Because, if exceeded the grid infrastructure needs be changed and a bigger transformer is necessary. Storing in the district could be achieved by storing electricity in the "free" available thermal mass of the building, or by storing in an electric battery. Storing in the thermal mass will be conducted by increasing the heating set point of the building. The residual power peak is stored in a battery. Three storage scenarios are evaluated: storage in the thermal mass of the building, storage in the battery and a combination of storing in the thermal mass and the battery. The case study is a business park in an early-design phase. An initial outlook of the business park will be evaluated. The simulation models are made in Modelica to represent the buildings, wind turbine, heating generation and district heating network. The whole site is controlled by a master controller with the aim to reduce the peak loads.

Results of the simulation shows the most of the power peaks can be lowered by applying on-site storage in buildings and the battery. This results in a reduction of 81.3%, during winter, from the amount of power above 1 MW in comparison with no storage. This results in less stress on the grid connection and no need for larger capacity of the transformer.

1. Introduction

The world population is growing by 1.2% per year (PRB, 2014), in addition the energy use per person increases as a result of the average wealth going up. This will result in a growing energy consumption of 56% between 2010 and 2040 (EIA, 2013). The increasing demand of energy, thus the demand for fossil fuels will lead to capacity problems. In 2015 78.3% of the total energy is produced by fossil fuels and 19.1% is from renewable sources (REN, 2015). With the use of fossil fuels, the environment is being polluted by the greenhouse gases. Furthermore, the production capacity and the availability of the easily accessible fossil resources cannot keep up with the increasing demand. Therefore, sustainable methods to generate energy are becoming important.

The European Commission made a climate regulation for 2020. In this year the members of the EU need to reach a 20% reduction of greenhouse gases compared to 1990, 20% of the energy must be sustainable and the total energy consumption must be reduced by 20% (Rijksoverheid, 2010). One of the important measures to reach these goals is renewable energy generation. This can be achieved by using renewable sources like wind, solar, water and biomass. Wind and solar power have an intermittent production profile which leads to problems like mismatch between production and consumption of energy.

The basic structure of the electricity system is shown in Figure 1. Generation stations produce electricity from various sources. Electricity from the generators is converted to higher voltages for transportation in bulk over the transmission lines. At the substation it is converted to lower voltages for distribution to customers. (RVO, 2016) Nowadays renewable energy sources are implemented at all stages of the electricity system. The extra electricity generation from the renewable energy sources leads to fluctuations on the connection between the district and the public grid. High electricity production will introduce stress to the grid connection, a transformer substation, the power on the grid connection is the generated electricity minus the electricity demand from the buildings. Increased electricity demand (EIA, 2013) in combination with renewable energy production requires investments in the power grid to accommodate these fluctuations. Investments like increased transformers capacity are high cost investments but are necessary to handle the power peaks.

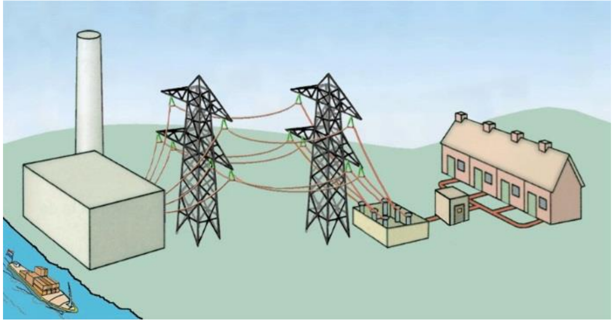

Figure 1 -Basic structure of Dutch electricity system (Straathof, 2015)

In order to reduce high peaks on the grid connection it is necessary to match the power production and the consumption based on demand response (Mengmeng, 2016). Peak load can be shifted by, storing electricity on-site during the time of surplus electricity production and then reusing in periods where the productions is not sufficient for the consumption (Barzin et al, 2015). Storing energy on-site could be achieved individually, per building, or centralized for a district. Modern districts want to match the local production to the local use, not only at a distributed level, but on a centralised level for a whole district or city level. To achieve this, energy needs to be shared. The fourth generation of district heating systems, which is currently under research, integrates with both smart grids and sustainable energy sources, thereby it is meeting the requirements of energy efficient buildings (Lund et al., 2014). The flexibility of these systems should be able to absorb the energy mismatch and reduce the total energy demand. Exchange of energy system throughout the district is called a smart energy systems (SES). SES tries to optimize energy efficiency and local resources by matching the energy demand to the supply. Such systems are more and more adopted into cities. Energy services companies, like ENGIE, design and develop SES systems as an answer to the power distribution and production for individual or collective solutions.

The purpose of this paper is to reduce the power peaks on the grid connection below 1 MW. A way to reduce the peak is by demand side control. Focusing on storing energy on-site by using the buildings thermal mass (passively) in combination with smart temperature control and electric battery storage (actively). The reduction of the power redelivery will be analysed in the early-design phase of an all-electric business park with two on-site wind turbines. For the three storage scenarios: storing in the buildings thermal mass, storing in the battery and combined storage in the buildings thermal mass and the battery. The A1 Deventer case-study considers six buildings; three buildings with a collectively district heating system, while the other three buildings are provided with an individual solution for providing their heating and cooling demand. All these systems are controlled by one master controller with the aim to reduce the peak loads. This configuration is analysed on the reduction of the power peak on the grid connection.

2. Previous work

The demand supply mismatch is becoming an increasingly big problem because of increasing use of renewable energy sources (Koutsopoulos and Tassiulas, 2012). Because of the increasing use of renewable energy sources the load profile on the transformers in the grid connections will increase as well. Transformers are the most expensive components in an electricity distribution system (Humayn et al, 2016). The peak loads determine the required capacity of a transformer. By reducing the peak power on the transformer cost can be reduced. Therefore, the total power peak on the transformer is an important quantity, that is the result of the production from the renewable energy sources with the subtraction of the demand from the buildings.

The thermal ISO 13790 model, from now on mentioned as ISO, is a simplified hourly model which calculates the space heating and cooling demands of a building (ISO, 2005). The model is based on five resistances and one capacitance. These resistances represent a heat flow through a building component (e.g. external wall, window ventilation). Heat flows are connected to nodes, which represent the ambient, the internal air, the surface and the mass temperature. The thermal mass of the building is represented by a capacitance. Furthermore, the heat flows from internal gains and solar radiation are connected to the corresponding nodes. The ISO model calculates the heating, cooling demand and simulates the response of a building by adding heat.

Modelling building systems becomes more complex, because of the different types of heat transfer mediums (e.g. air, water etc.) This imposes the need of flexible, multi-domain simulations models. These models should be applied during the design phase to accurately predict energy performance of buildings (Pasini, 2009). To have more modeling capability during the design phase, the modeling language Modelica is proven to be suitable and beneficial (Soons, 2014).

Modelica, is an equation-based object-oriented language that is able to model dynamic systems. This results in a language which is able to model the natural environment. Modelica is used for multi-domain systems, which allows the combined modelling and simulation of electrical, mechanical, thermodynamic, hydraulic and various other systems. These features make Modelica suitable for computation applications with increased complexity, such as a SES

In previous work, Soons (2014) created a district heating Modelica model based on eight buildings represented by the thermal model ISO. The building models are connected by a district heating network which gets its heat from a biomass gasifier. The ISO model in Modelica created in this previous work is the starting model for this research. By combining these ISO models a district could be modelled.

There are Modelica libraries related to the build environment. The Modelica Buildings library is a free open-source library with dynamic simulation models for building energy and control systems, developed by Lawrence Berkeley National Laboratory (LBNL) (Wetter, 2010). The Catholic University of Leuven (KU Leuven) developed the Integrated District Energy Assessment by Simulation library (IDEAS, 2015). This library allows simultaneous transient simulation of thermal and electrical systems at both building and feeder level. The Buildings library and the IDEAS library are used in the development of this study.

3. Case study

ENGIE is committed to develop a smart district energy system for a business park in development, called A1 Deventer. The use of gas is not possible in this district, so an all-electric solution is necessary. There are two wind turbines available on-site which will produce direct electricity for this business park. Normally wind turbines are connected to the main public grid and from the main grid renewable energy is consumed. A1 Deventer is a unique situation, the produced electricity from the wind turbines could be use before it is connected to the main public grid. It enables ENGIE to monitor, control, and optimize a supply and demand strategy for the business park. Currently, there are no companies settled on the business park. The expectations are warehouses, workshops with office functions, and a hotel will settle on-site in the near future. Resulting for this study, a scenario with three offices, two warehouses and one hotel is chosen. In the case study a combined heating solution and an individual heating solution will be used. The combined heating solution consists of a small district heating (DH) network with a heat pump used for heating. This network consists of two offices and one warehouse. The other buildings, office, hotel and warehouse, have their own heat pumps. Because the buildings are too far apart for a connection to the DH-network. It is therefore economically more feasible to have an individual solution then connected to the DH network. One turbine produces sufficient electricity for the six buildings in this case study. The outlook of the case study is shown in Figure 2. The parameters of all the buildings used in the Modelica model can be found in appendix A. As result, this case study will be evaluated on reducing the power peaks on the transformer.

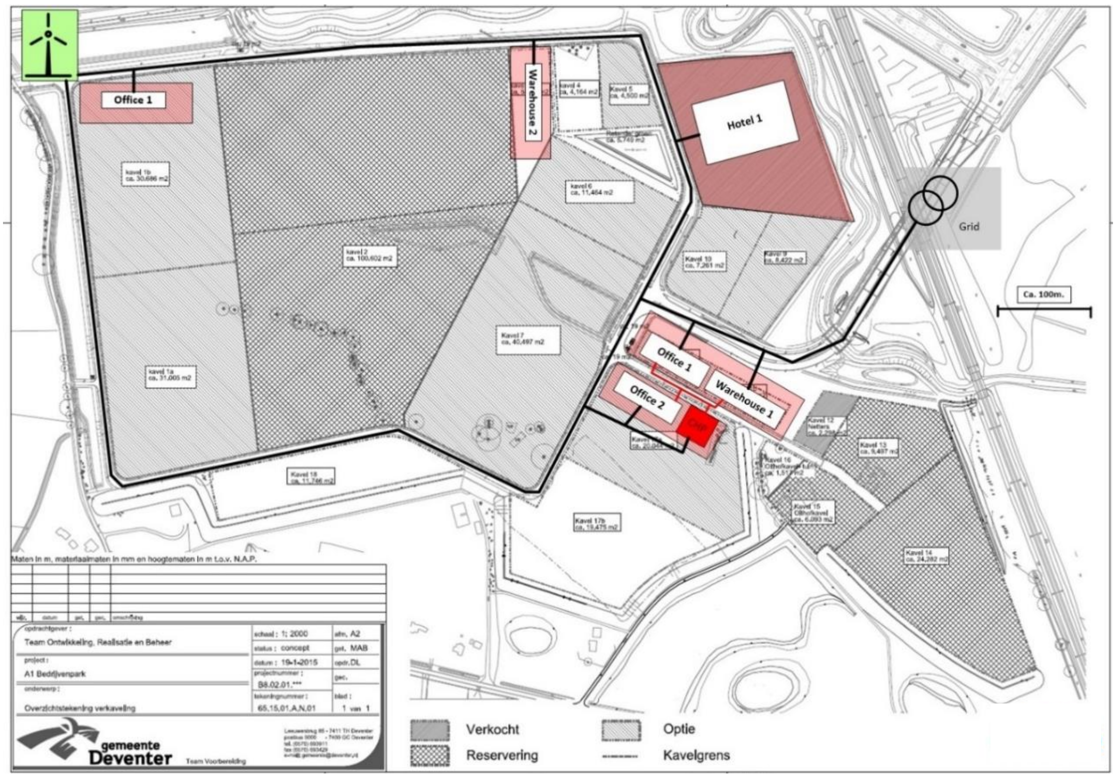

Figure 2 - A1 Deventer outlook

4. Methodology

In this section the proposed methodology is presented. In Figure 3 the process during this research is shown. First, the energy supply is determined, in order to show the possible peaks on the grid connection. Second, method of modelling the building demand of buildings is explained. Third, this building demand is calibrated to available measure data of the real building. Forth, the demand of each individual building needs to be aggregated to a total district demand. Finally, this step consists of introducing the possibilities to reduce the power peaks and evaluating the reduction of the peaks.

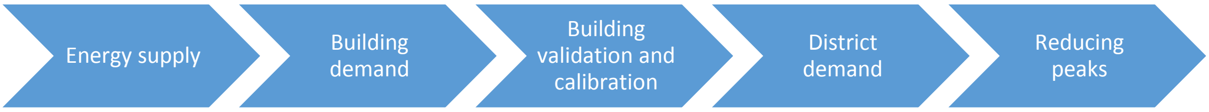

Figure 3 - process step during research

4.1 Energy supply

The electricity loop will provide electricity either from wind turbines or, if this is not sufficient, from the public grid. In Deventer, two 2.35 MW wind turbines are placed. The two wind turbines will annually produce 9.4 million kWh electric energy (Raedthuys, 2014). The wind turbine will be represented by a component (*Buildings.Electrical.AC.ThreePhasesBalanced.Sources.WindTurbine*) from the Buildings library that simulates the on-site power production. The power curve is used in the component to calculate the power output, shown in Figure 15 in appendix B. The inputs of the existing model are changed, to simulate the Enercon E-92, the type of wind turbine (Enercon, 2015). In the simulation model one wind turbine is used. One turbine produces sufficient electricity for the six buildings in this case study.

4.2 Building Demand

Modelling the building demand is performed in Modelica. The existing ISO model is improved by making the different components modular and increasing functionality. These components are Building, Weather, Occupancy, Ventilation and Thermostat. These components will be simulated for determining the heating, cooling and electricity demand of the building. The new building model in Modelica is shown in Figure 4. All the components will be discussed below. For the development the component the Buildings library and the IDEAS library were used.

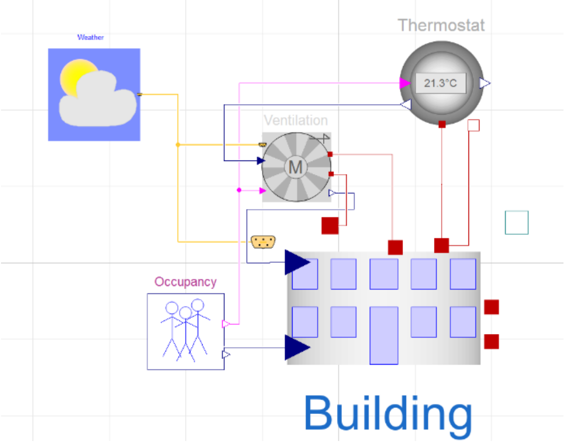

Figure 4 - Modelica model of a building with all the components

Building: The building component in Modelica is the extended ISO model. This existing component simplified and input parameters are combined or calculated in the component to limit the input parameters of the building. Therefore, it is possible to simulate a building with limited information. The information is the length, width, height, number of floors, year of built, window to wall ratio and internal gains of a building. The building component could use predefined parameter from a database; e.g. the Dutch building code with the minimum isolation values and the thermal mass. Other components (e.g. occupancy, ventilation, thermostat) have influence on the performance of the buildings. The ISO model is changed in order to connect the components to the ISO model and to take the influence of the building performances into account.

Weather: The weather of Deventer should be use to represent the weather on the business park, but there is no data available. But the KNMI has a weather file from Heino a place 25 KM away from Deventer. The weather data reader component in Modelica is used to read the weather data and to use it as an input for the model (*Buildings.BoundaryConditions.WeatherData.ReaderTMY3*). This component can read the format of TMY3 weather files. Therefore, an excel sheet is made to convert a KNMI weather file to the correct TMY3 format. After the conversion it is possible to use a KNMI weather file in the Modelica weather data reader.

Occupancy: Buildings are occupied during the working hours of the company. The occupancy of the building influences the internal gains in the building. Therefore, occupancy of a building should therefore be taken into account for the calculations. The occupancy component in Modelica is used to simulate this aspect. In the component of the Buildings library a schedule can be inserted (*Buildings.Controls.SetPoints.OccupancySchedule*). However, this component can only simulate a fully occupied or unoccupied situations, while occupancy rises and decreases in reality. Therefore, the component is extended to simulate the rise of the occupancy level and the decent at the begin and end of the day. Furthermore, the building is not entirely shut down at night. Some devices could stay active, such as emergency lights, computer screens, coffee machines, etc. These devices will generate heat and use electricity. To simulate these internal gains and electricity demand a signal from this occupancy component needs to stay on at night. The percentage of the remaining night electricity use can be given as input. (default at 20%, obtained from the analysis of the ENGIE building in Maastricht). Different records of a weekly schedule can be used as an input for this component. The output signal of this component sends to the building component influences the internal gains.

Ventilation: A ventilation system provides fresh air inside a building. With a possibility of implementing a heat recovery unit in this system some heat is reused. The ventilation component in Modelica is used to determine the amount of heat which is recovered from the room and in combination with the external temperature redelivered to the building. The percentage of heat recovery can be given as an input in the component. The controller of the heat recovery of the ventilation component is shown in Figure 5 . Either the outside air, or the combination of outside air with recovered heat will be redirected in the building component. If the external temperature is greater than the external temperature and the set point, the recovery is shut down, and the external temperature is used. The air changes per hour (ACH) are also given as output of this component. This is then used as input for the buildings component, in the ventilation resistance of the ISO model.

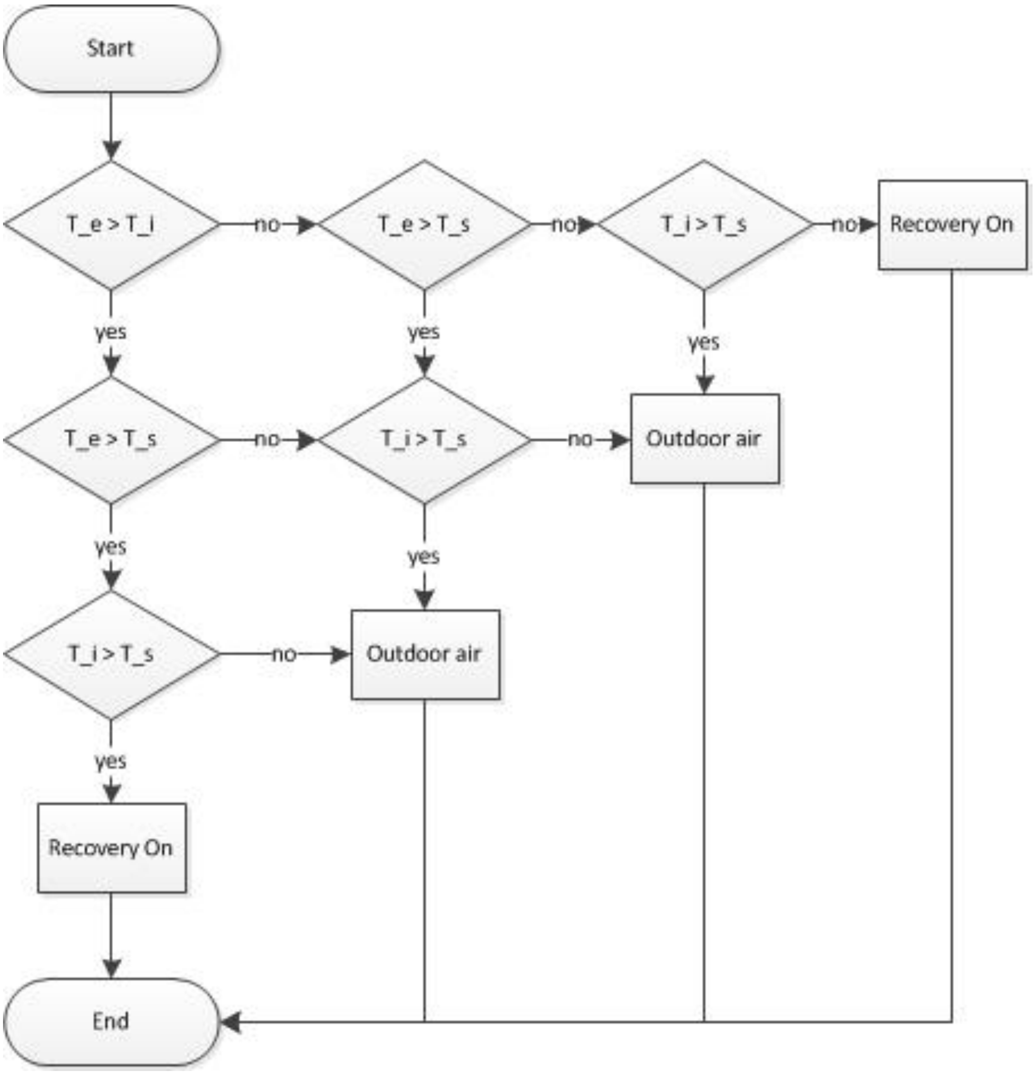

Figure 5 - controller of the heat recovery in ventilation component

Thermostat: In the thermostat of a building the heating set point could be given. Dependent on this set point the thermostat will activate the heating or cooling generation in a building. The building on A1 Deventer needs a temperature controller. The thermostat component in Modelica calculates the heat and cooling demand necessary to satisfy the temperature according to the temperature set points of the building. The component to control the heating and cooling uses two PID controllers. A temperature sensor detects the room temperature, which is used as the reference signal for the two PID controllers. One controller compares the temperature with the heating set point and the other controller compares the temperature with the cooling set point. If the temperature is below the heating set point or above the cooling set point the difference between the temperature of the room and the set point is processed to get the amount of heat or cooling required to satisfy the temperature set points. This amount of heat or cooling is used as output from the thermostat and as input in the internal temperature node of the buildings component.

Together all these components, with all the parameters and set points, are able to simulate the performance of a building. The model calculates the heating, cooling and electricity demand.

4.3 Building validation and calibration

The simulation model is used to predict the performance of a building and calculate its energy demand. To check if the simulation demand matches the reality, validation of the model is needed. An existing building will be modelled and simulated, the results will be compared. Simulation results are evaluated by calculating the coefficient of variation – root mean square error (CV-RMSE) that indicates the overall uncertainty, and the mean bias error (MBE) that indicates how well the energy consumption is predicted. The equation to determine the error values are shown below. The ASHRAE made guidelines to determine reliability of a model, whenever the CV-RMSE and the MBE confirm the guidelines (ASHRAE, 2015). According to the guidelines the acceptable values are 15% for CV-RMSE and ±5% for MBE. If the results do not match the guidelines the model needs calibration in order to reduce the error values. For calibration the signature method is used (Claridge, 2003).

$$RMSE = \sqrt{\sum \frac{(S-M)^2}{n-2}} \tag{1.}$$

$$A = \frac{\sum(M)}{N} \tag{2.}$$

$$CV(RMSE) = \frac{RMSE}{A} \times 100 \tag{3.}$$

$$MBE\ (\%) = \frac{\sum(S-M)}{n} \times 100 \tag{4.}$$

4.4 District demand

The building models simulate two types of demand, an electricity demand and a thermal demand. For the electricity demand each building is connected to the electricity loop on-site. Furthermore, the thermal demand will be satisfied either by an individual heating solution or a combined heating solution.

The individual heating solution, an air-to-water heat pump, is connected to the electricity loop on-site. Electricity from this loop will be converted to thermal energy. To satisfy the space heating demand of the building the heat pump must generate enough heat. Thereby, the amount of energy the heat pump can produce is dependent on the coefficient of performance (COP). COP depends among others on the temperature difference between the evaporator and the condenser. The temperature of the evaporator is the ambient temperature and the temperature of the condenser is the temperature of the production circuit. The IDEAS library of Modelica contains an air-to-water heat pump component (*IDEAS.Fluid.Production.HP_AirWater_TSet*). This component will simulate the air-to-water heat pump and calculates the electricity demand to satisfy the heating demand of the building calculated by the ISO model. The combined heating solution consists of a DH network and a piping network connected to every end user, to extract heat for the network to use for the building. The piping network is modelled as an underground pipe system, it covers a distance of 300 meters, taking into account the Kusuda model for thermal losses to the ground (Kusuda & Achenbach, 1965). The network is connected to an air-to-water heat pump; this is the heat generation for the district heating network. The supply temperature of the DH network is set to 50°C. Each building connected to the DH network has a heat exchanger to extract heat from the DH network to the building. From water loop of the building the heat is extracted to satisfy the building heat demand. The combined heat pump will keep the heat in the network to 50°C. The electricity needed for the combined heat pump and for the individual heat pumps are extracted from the electricity loop as well the electricity needed for the plug loads.

4.5 Reducing power peaks

Together the production and consumption of electrical energy will lead to a fluctuating power profile on the grid connection. The surplus electricity is delivered to the public grid, resulting in high power peak on the grid connection. In order to lower these power peaks on-site storage is needed. If the power on the grid connection exceeds the maximum amount of power, the surplus of produced electricity should be stored on-site. The storage needs to be evaluated, this will be done with key performance indicators.

4.5.1 On-site energy storage

Three storage strategies are introduced: Firstly, free on-site storage is available since all the buildings have a thermal mass which can store power. All the buildings will be heated up to a master set point in order to store more electricity in the building. Secondly, storage in a battery package will be applied until the battery is full. In this case is electricity from the grid will be consumed, first the stored electricity form the battery will be used until the battery if fully discharged. Thirdly, a combination of the storage in the building and in the battery will be applied. The two components, master thermostat and battery, are developed to control the on-site storage.

Master thermostat: This component changes the heating set point of all the buildings in order to store more power in each building. The controller of the master thermostat is shown in Figure 6a. The heating set point of all the buildings will be raised if the power on the grid connection exceeds 1 MW. To prevent fluctuation, a higher set point will be applied for a minimum of one hour. After one hour the controller will be run again. The higher heating set point results in a higher heating demand in all the buildings. Subsequently, this results in a higher electricity use of the heat pumps to satisfy the heating demand. Therefore, the power to the grid connection will decrease.

Battery: The battery used for this case is based on the information of the Tesla powerpack, a flexible and infinitely scalable modular Lithium-ion battery (Tesla, 2016). Each powerpack contains 100 kWh batteries and 250 kWh bi-directional inverters could be applied. For this case we make use of 54 powerpack to create a 5,4 MWh battery with a peak power of 500 kW. In Modelica a battery component from the Buildings library is added to represent the Tesla powerpack. The charge and discharge efficiency are set on 91%. The battery has a control strategy in order to store the surplus power above 1 MW, shown in Figure 6b. If electricity injected to the public grid is above 1 MW, the battery starts charging for a minimum of 15 minutes. The minimum is taken into account to prevent large fluctuations and a longer simulation time. The battery will be charged until it is almost full. The state of charge (SOC) is then 0.99. If the electricity is consumed from the public grid, the battery will be discharged first until the SOC is 0.01.

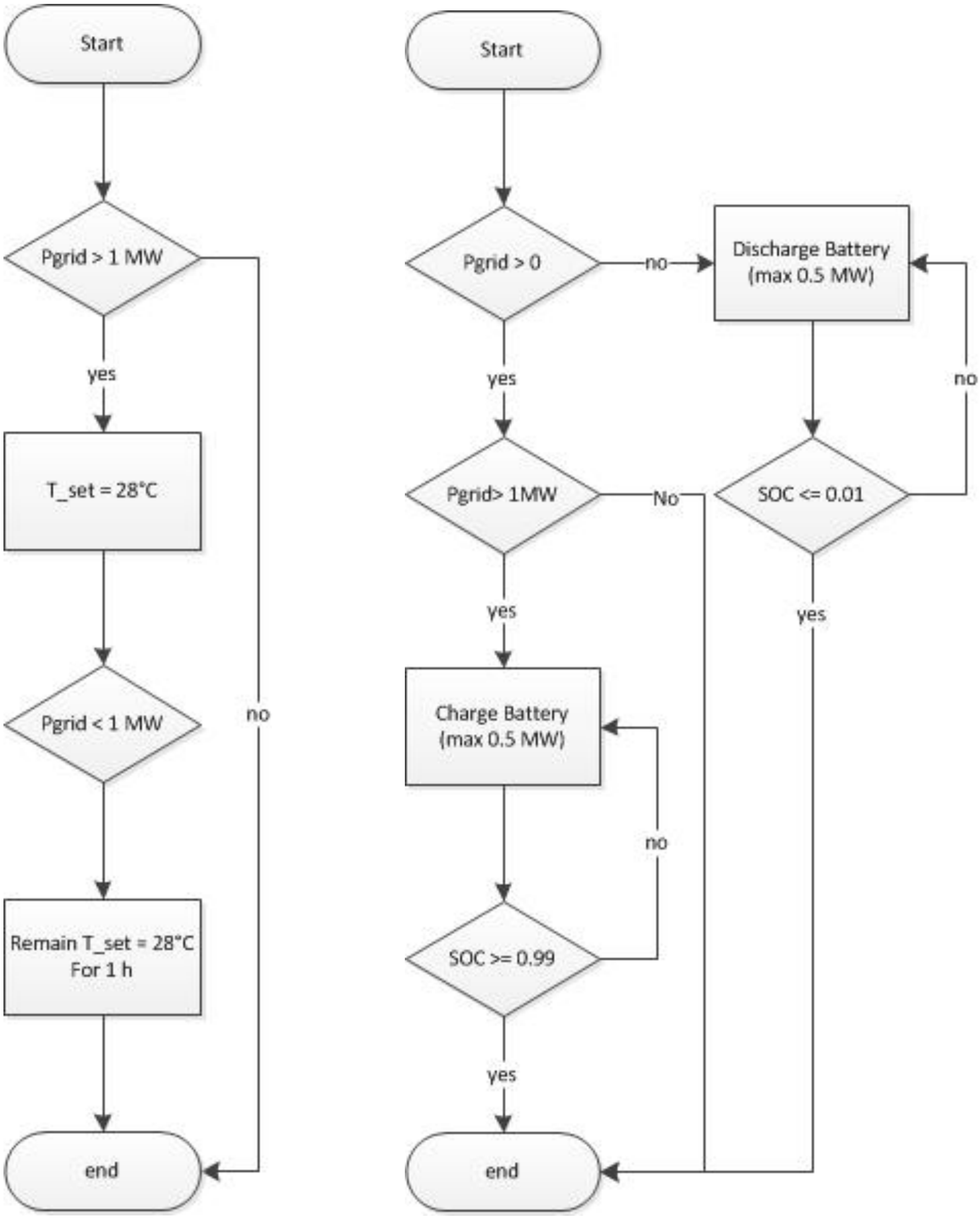

Figure 6 – a) Controller of the master thermostat, b) Controller of the battery

4.5.2 Key performance indicators

First, the evaluating period is determined with the annual generation of the wind turbines. Two periods, winter and summer, with a high density of high power peaks will be determined from the annual generation Those two periods will be used to evaluate the possibility of lowering the power peaks on the grid connection. Second, four different scenarios will be analysed during these two periods. The scenarios are: (1) base case without storage, (2) storage in buildings, (3) storage in battery and (4) storage in both buildings and battery.

In order to quantify the (mis)match between the production of the renewable energy and the consumption of the energy, the matching indices from Cao et al. (2013) are used: The On-Site Energy Fraction index (OEF) and the On-Site Energy Matching index (OEM). The OEF represents the part of the load covered by the on-site energy production, while the OEM represents the part of energy produced on-site used by the building and the systems. The equations of the matching indices are given below:

$$OEF = \frac{\int_{t1}^{t2} Min[G(t); L(t)]dt}{\int_{t1}^{t2} L(t)dt} \; ; \; 0 \leq OEF \; \leq 1 \qquad 5.$$

$$OEM = \frac{\int_{t1}^{t2} Min[G(t); L(t)]dt}{\int_{t1}^{t2} G(t)dt} \; ; \; 0 \leq OEM \; \leq 1 \qquad 6.$$

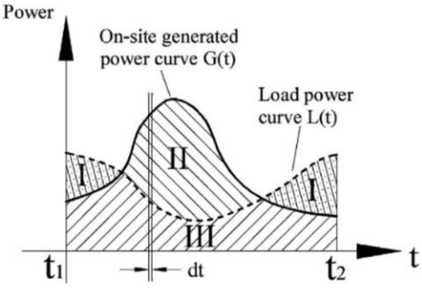

Figure 7 - Illustration of OEF and OEM (Cao et al. (2013))

Figure 7 represents the principle of the equations. The values of the OEF and the OEM close to one mean a higher matching. To consider the different types of energy which could possibly have the mismatch, Cao et al. (2013) extended the OEF and OEM indices. The principle remains the same, however the index is specified separately for electricity and heating. OEF_e, OEF_h, OEM_e and OEM_h are indicators for (e) electricity and (h) heating. Since no cooling system is considered in this study, the OEF_c and OEM_c serve no purpose. The following equations are used in this study to represent the case study.

$$OEFe = \frac{\int_{t1}^{t2} Min\left[G_{elec}(t) - \; ES_{on}(t); L_{elec}(t) + E_{off-h}(t) + E_{on-h}(t)\right]dt}{\int_{t1}^{t2} [L_{elec}(t) + E_{off-h}(t) + E_{on-h}(t)]dt} \qquad 7.$$

$$OEF_h = \frac{\int_{t1}^{t2} Min[H_{eon-h}(t); L_{heat}(t)]dt}{\int_{t1}^{t2} L_{heat}(t)dt} \qquad 8.$$

$$OEMe = \frac{\int_{t1}^{t2} Min[G_{elec}(t); L_{elec}(t) + E_{on-h}(t) + \; ES_{on}(t)]dt}{\int_{t1}^{t2} G_{elec}(t)dt} \qquad 9.$$

$$OEMh = \frac{\int_{t1}^{t2} Min[H_{eon-h}(t); L_{heat}(t)]dt}{\int_{t1}^{t2} H_{eon-h}(t)dt} \qquad 10.$$

Furthermore, the time storage is active is determined to see the influence of control strategy. Also the percentage of lowering the peaks is determined. Meaning the total amount of energy is store during peaks above 1 MW by the different storage scenarios.

5. Results

In this section the results of this research are presented. First, the result of validation and calibration the model are presented. Second, the determination of the evaluation period is presented. Third, power fluctuations on the grid connection are shown for the different scenarios during the evaluation period. Fourth the mismatch between production and consumption and the effectiveness of peak lowering is presented.

5.1 Validation and calibration

Validation of the buildings simulation model is conducted by simulating the building of ENGIE Zuidoost, located at Amerikalaan 35, Maastricht-Airport. The measured gas consumption data is compared with the simulated results from Modelica. The compared period is from 1st of December 2014 until 30th of November 2015. The real gas consumption of the building is measured. If the result of the simulation is comparable with the measure data the model could be used, if not the model should be calibrated.

Assumptions have been made to represent the ENGIE building in the simulation model. The ISO model is only able to calculate with rectangle shapes and not complex shapes. However, the floor plan of the ENGI building is a H shape, therefore it is simplified to a rectangle shape. Hence, the total floor area and surface area will remain the same. All the parameters used in the simulation model are shown in appendix C.

Table 1 - Results of the buildings calibration

	CV-RMSE	MBE	Measure gas use (Nm^3/a)	Simulate gas use (Nm^3/a)
Un-calibrated	308.86%	199.94%	17787.3	53350.95
Calibrated	21.44%	0.61%	17787.3	17895

The CV-RMSE and MBE Values of the initial simulation results are unacceptable (Table 1). According to the guidelines the acceptable values are 15% for CV-RMSE and ±5% for MBE. A significant share of the error values are reduced after the calibration. This is caused by changing the isolation values, heating set point and the temperature of the ventilation air showed in Table 2. After calibration the MBE value is decreased within the guidelines by the calibration. The residual CV-RMSE is outside the specification of the guidelines. This can be attributed to assumptions made because the ISO model. The model consists of one zone instead of the multiple zones in the real building. The thermal mass of the building would be higher because the internal thermal mass is not taken into account (e.g. indoor wall, furniture, etc.) Despite of all these assumptions, the simulated annual gas use after calibration is only 0.6% off. Therefore, this model is comparable with the measured data. This model is used as one of the individually heated buildings in the case study (office 2).

Table 2 - Changed parameters of the building during calibration

	Un-calibrated	**Calibrated**
Isolation (RC-value) [m^2K/W]	Roof = 2.5 Wall = 2.5 Floor = 2.5 Window = 0.24	Roof = 2.1 Wall = 5.5 Floor = 2.1 Window = 0.7
Heating set point	T_min = 16°C T_set = 21°C T_max = 24°C	T_min = 23°C T_set = 23°C T_max = 24°C
Ventilation temperature	T = 20°C	T = 22°C

5.2 Evaluation period

Figure 8 shows the electricity generation in A1 Deventer by the wind turbines for a year. Periods with high peaks will have the most surplus electricity. Consequently, this is resulting in high peaks on the grid connection, therefore, these periods will be evaluated. Two periods will be selected, one in winter and one in summer, both having different external temperatures. Analysing the graph results in the following evaluation periods. For the winter period the month February and for the summer the month August.

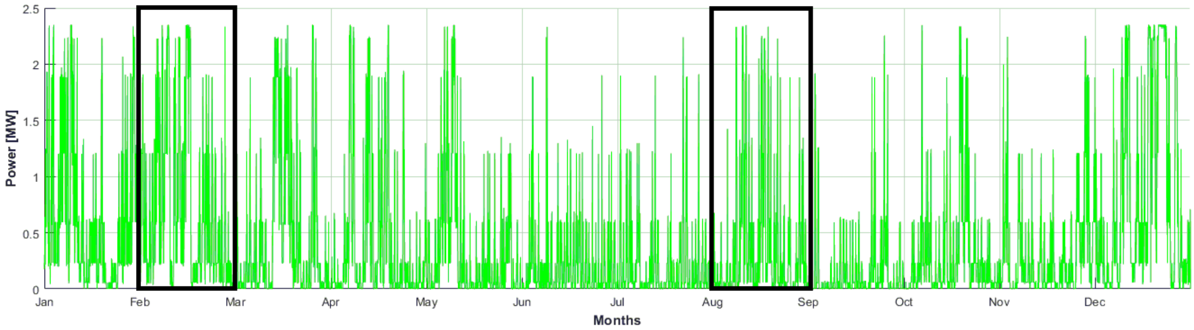

Figure 8 - Generated power from the wind turbine

5.3 Fluctuations on the grid connection

Figure 9 shows the power fluctuation on the grid connection for the different scenarios during the winter month. On the y-axis the amount of power transmission on the grid connection is shown and on the x-axis the day in February. It is showing storing power on-site results in a decrease of the power peaks on the grid connection.

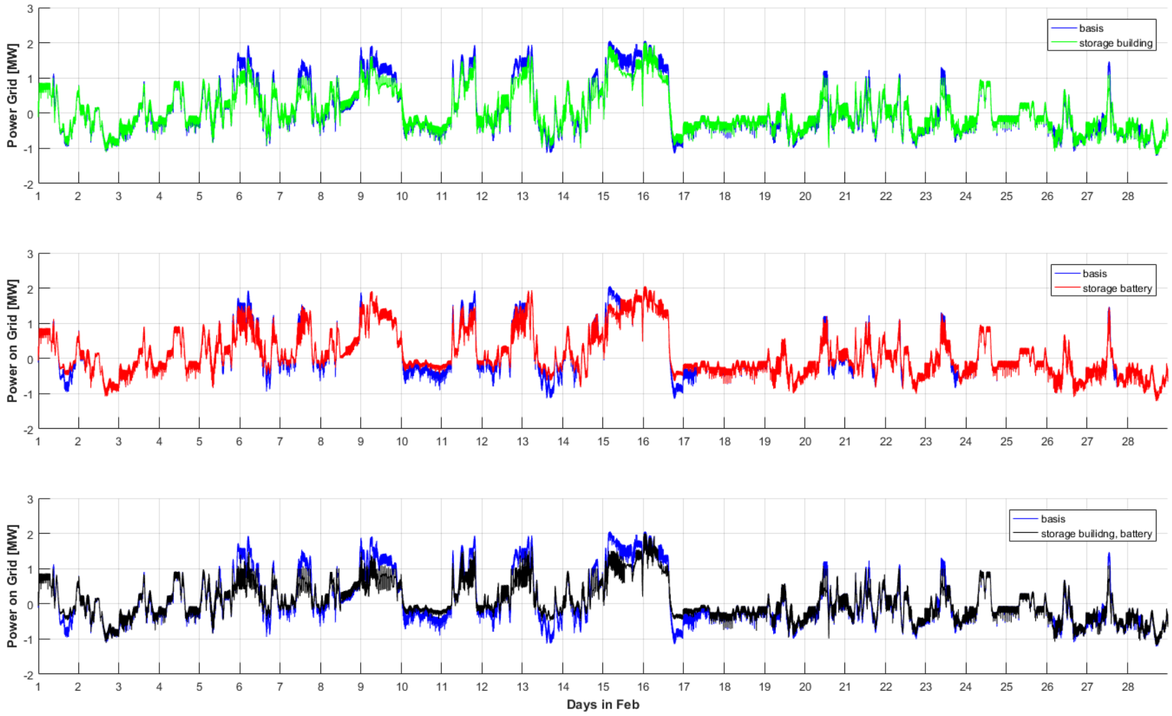

Figure 9 - Power fluctuation on grid connection for February (a) storage in building (b) storage in battery (c) storage in building and battery

To observe the results more into detail a few days are evaluated, shown in Figure 10. It shows increasing the heating set point of the building results in constant lowering the high peaks, because more power is needed to satisfy the higher heating demand. (Figure 10(a)) Storing power in the battery results in lowering the peak above 1 MW for the time until the battery storage is full. However, the power peaks consumed from the grid are also lowered, by discharging the battery (Figure 10 (b)). The most peaks are lower by the combination of storing power in the building and in the battery it results in more storage in the building as well as in the battery (Figure 10 (c)).

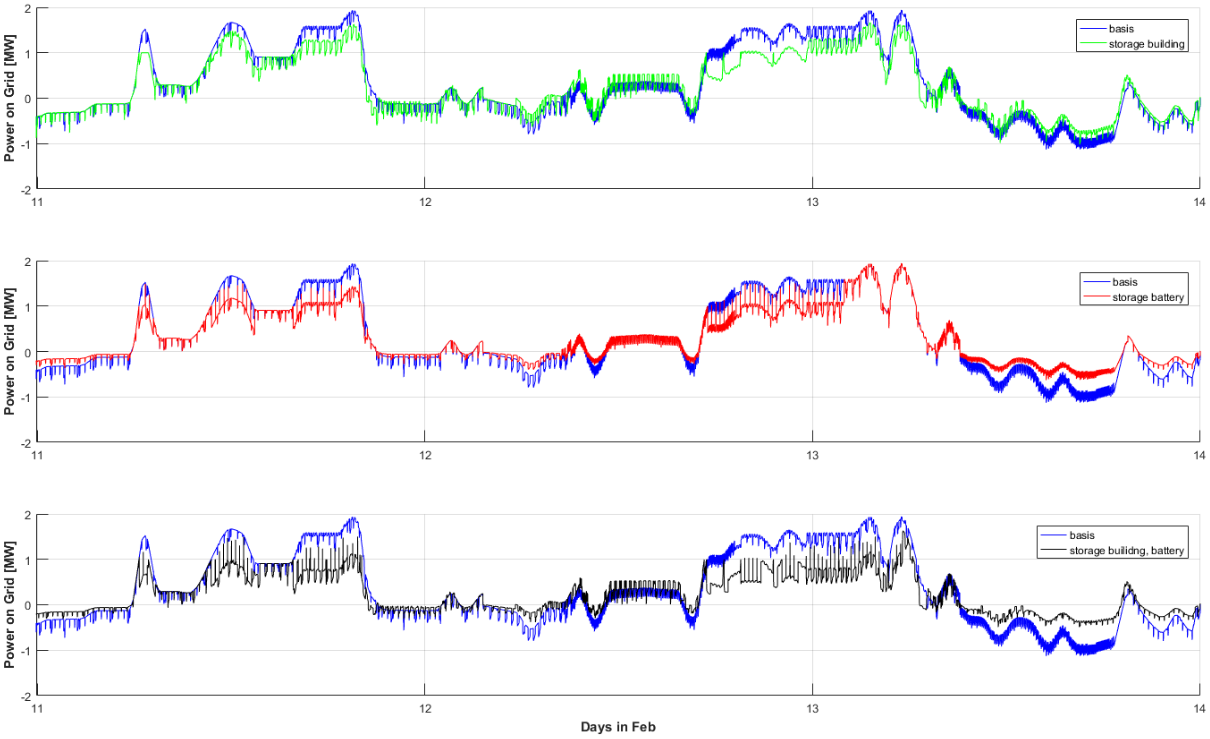

Figure 10 - Power fluctuation on grid connection for three days in February (a) storage in building (b) storage in battery (c) storage in building and battery

Figure 11 shows the time the storage is activated for the three different storage scenarios. The master set point shows when the thermostat of all the building is raised in order to store power in the building. The SOC shows whether the battery is charging (SOC increasing) or discharging (SOC decreasing).

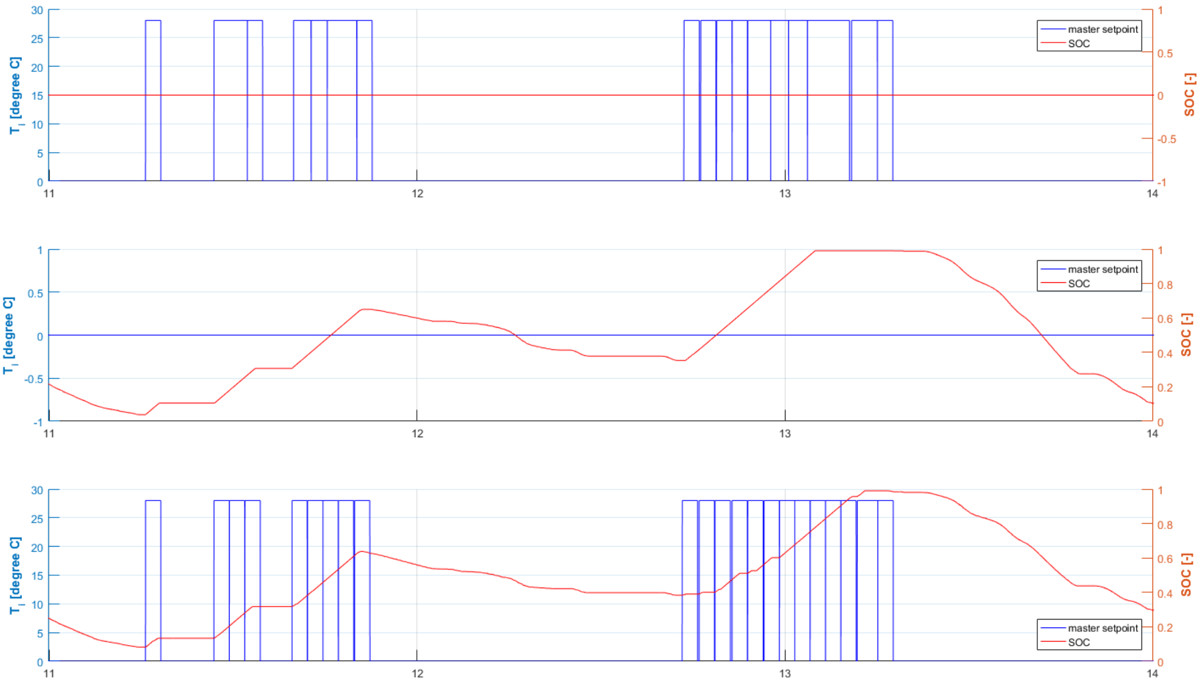

Figure 11 – Activated storage during three days in February (a) storage in building (b) storage in battery (c) storage in building and battery

When storing power in the buildings the temperature set point of all the buildings is raised to 28°C, the master set point, otherwise the temperature set point is following given heating set point from the input parameter (appendix A). Figure 12 shows the indoor temperature of office 1 during the winter month for all the three storage scenarios. The raised temperatures are mostly happening when a building is not occupied, after work hours or in the weekend. Because at these moments the buildings have a lower demand, therefore the power on the grid connections is raised.

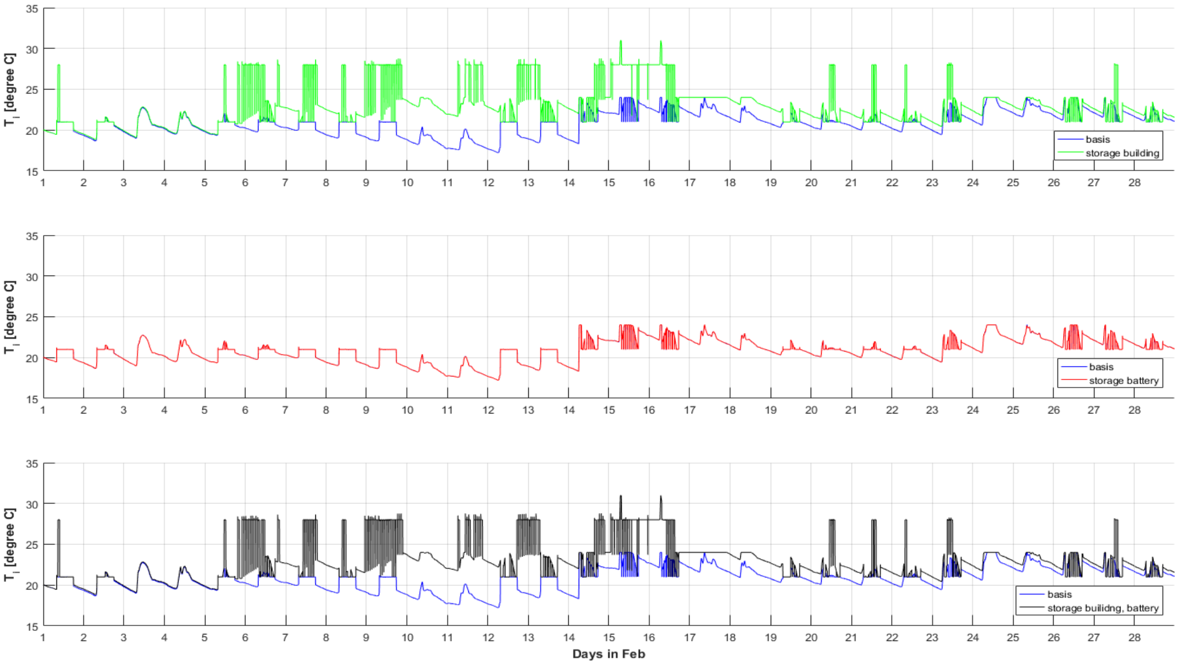

Figure 12 – Indoor temperature of office 1 in February (a) storage in building (b) storage in battery (c) storage in building and battery

The same figures are made for the summer month these can be found in appendix D.

Some extra number about the winter period are taken. These number can be found in table 3. The maximum peak is not changed by the storing solutions but the mean peak is lowered by storing more power. Also the time the peaks occurred is lowered a lot.

Table 3 - Numbers of the winter period storage

	Max peak (MW)	Mean peak (MW)	Number of peaks > 1MW	Time peaks occur (h)
Basis	2.05	1.40	210	104
Building	2.00	1.33	161	56
Battery	2.05	1.35	291	63
Building + Battery	2.00	1.32	227	28

5.4 Key Performance indicators

Figure 13 shows the matching indices during for the different storage scenarios. It shows a better matching is obtained with the increased storage scenarios. The OEFe shows the electricity load is more covered by the production of the wind turbines. The OEMe fraction of on-site produced electricity which is used by the building, but there is more produced. The OEFh shows the heating production is more covered by the on-site generated electricity form the wind turbines. Furthermore, the OEMh shows the fraction of on-site produced heat, from the electricity from the wind turbines, in relation to the total generated heat.

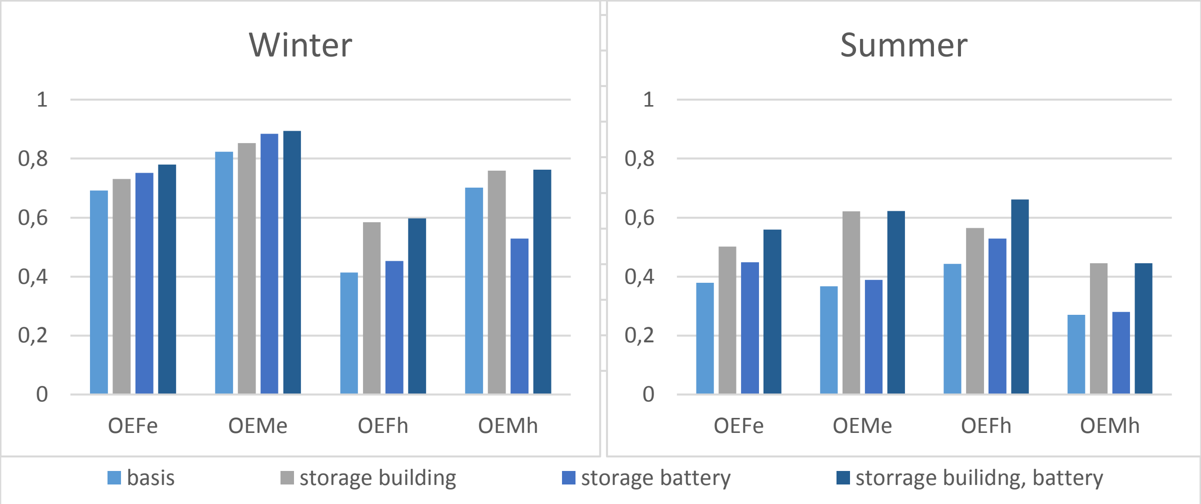

Figure 13 - Performance indicators

Table 4 shows the results of the different storage scenarios for the winter and the summer. Storing energy in the building increase the heating demand of the buildings a lot. In the base case the buildings require 293.85 MWh during the winter. By storing energy in the buildings, when power on the grid connection exceed 1 MW, the heating demand of the building is raised to 400.41 MWh. Due to the fact the temperature set point is raised to 28°C. Also during the summer the heating demand is increased from 17.63 MWh to 56.78 MWh by storing energy in the building. During the summer period the total district heating demand is substantially lower due to the fact the outdoor temperature is higher and the heating demand of the building is satisfied quicker. Also the storage in the building is much lower due to the outdoor temperature. Total reduction of peaks above 1 MW is not achieved. Table 4 shows the percentages of total energy from peaks above 1 MW which lowered by the storage. The combination of storage in the building and battery reduces the total energy above 1 MW by 81.3% during winter and 69.2 % during summer. In the winter the total storage, building and battery, which can be achieved is 129.72 MWh, during summer 61.51 MWh is stored. Therefore, the combination of storage in the building and in the battery minimize the redelivery of power peaks above 1MW, for the evaluated configurations and periods.

Table 4 – Results storage

	Winter (Feb)			Summer (Aug)		
	Total district heating demand (MWh)	Stored energy (MWh)	storage active (h)	Total district heating demand (MWh)	Stored energy (MWh)	storage active (h)
Basis	293.85	-	-	17.63	-	
Building	400.41	106.56	124	56.78	39.14	65
Battery	293.85	28.18	58	17.63	23.76	48
Building + Battery	400.25	129.72	124 + 52	55.83	61.51	64 + 47

Table 5 – Percentage of energy above 1MW is reduced

Percentage reduced	**Building**	**Battery**	**Building + Battery**
Winter (Feb)	62.8%	36.6%	*81.3%*
Summer (Aug)	18.5%	59.6%	*69.2%*

6. Conclusion

This research was about reducing the power peaks on the grid connection. The case study an all-electric business park in the early-design phase is evaluated. A simulation model is developed in Modelica. Validation and calibration proved model is able to represent a building.

The evaluation of the different scenarios for the case study shows a reduction of 81.3% can be achieved, in the total amount of energy when the 1 MW limitation is exceeded. This involves storing power in both the building and the battery. During this evaluated month, February 2014, the heating demand of the buildings is increased from 293.85 MWh to 400.25 MWh and 23.32 MWh is stored in the battery. During this month 124 hours the heating set point is increased to 28°C and 52 hours the battery is charged. Most of the 124 hours of the increased heating set point are during times the buildings are unoccupied. In figure 12 the electricity on the grid connection is shown. The black line represents the storage in the building and battery and shows the reduction of peaks above 1 MW

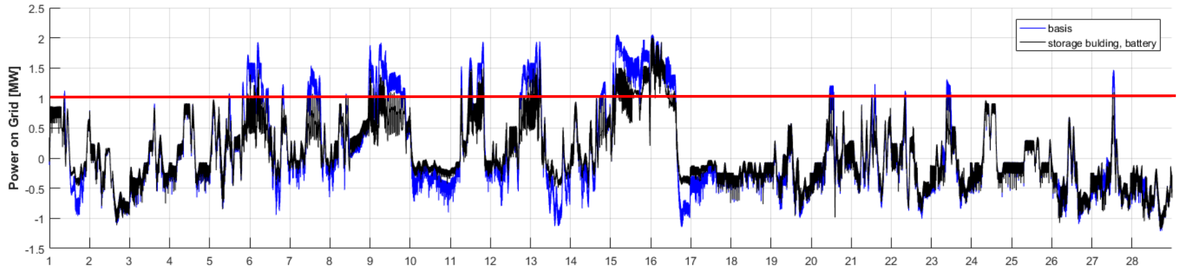

Figure 14 - Power fluctuation on grid connection for February with storage in the building and battery

During summer the outside temperature is higher. Heating demand of the building will be achieved with less effort. Consequently, less energy can be stored in the building during the summer comparing to the winter. The amount of energy stored in the battery remains almost the same. Despite less energy could be stored in the building, a reduction of 69.2% of peaks can be achieved by storing energy in buildings and batteries.

By storing the power peaks in the building, by heating up the buildings, ‘free’ available storage is used. While storing in the batteries requires an extra investment for the development of the business park. Finally, from the results can be concluded that storing power on-site, in the building and in a battery, can contribute on lowering the power peaks. Total reduction of peaks above 1 MW is not achieved but the 81.3% of the peaks are reduced, during winter period. This provides lower loads on the transformer between the business park loop and the public grid.

7. Discussion

This research was about the lowering the peaks redelivered to the grid connections. To prevent power peaks exceed the 1 MW limit further research is needed. Different types of generation systems could be determined and evaluated. Here a solid choice could be made for the best heating generation system for the case study. This research was adapted to investigate the possibility of storing energy in a building by heating up the buildings. If the temperature of 28°C is desirable is being disregarded in this research, therefore in further research the influence of this high temperature set point needs to be investigated. This high temperature could result in overheating hours during the occupancy hours, which should be prevented. After the increased heating set point of 28 degrees is lowers to the original heating set point it looks like the building is actively cooled. This needs some further investigation to see if indeed the system is actively cooling the building, this should be prevented.

8. Future work

The power peaks still exceed the 1 MW limit further research is needed to prevent the peaks exceed the limit. Therefore, the amount of power stored on-site could be increased. The battery capacity could be enlarged and a thermal energy storage can be added. To extend the current model, domestic hot water use and cooling systems could be added to better approach reality. Furthermore, ‘free’ on-site storage could be increase during summer by extra cooling the building. During summer the temperature of the building is higher and therefor cooling is preferred. If the increased heating set point of 28°C is desirable needs some investigation. Another opportunity is to increase the set point during occupancy to 25°C and if the building is unoccupied to 31°C. This could result in less overheating hours and lowering more of the peak on the grid connection. Also the extreme which occurred on the grid connect is not lowered a lot, this should be lowered so the extreme numbers of the power should be reduced.

9. Acknowledgments

This paper is a master thesis for the master program Building Physics and Services at Eindhoven University of Technology in collaboration with ENGIE Netherlands. I would like to thank Frank Soons, from ENGIE, for his advice, support, help and supervision during the graduation process. Furthermore, I would like to thank Professor Jan Hensen, Ignacio Torrens and Luyi Xu who advised me by giving me feedback and for guiding me through the process. Also I would like to thanks my friends and family for their unconditional support and trust. Especially Kim, Rob, Christiaan, Dirk and

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Appendix A – Settings buildings A1 Deventer model

	Office 1	**Office 2 (ENGIE)**	**Warehouse 1**
Building			
L	30 m	20 m	80 m
B	25 m	106 m	100 m
H_floor	3 m	2.7 m	5 m
n_floors	3	4	1
Qi	15 W/m2	15 W/m2	15 W/m2
Plugload	10 W/m2	10 W/m2	10 W/m2
WW_ratio_north	0.4	0.16	0.3
WW_ratio_east	0.4	0.49	0.3
WW_ratio_south	0.4	0.15	0.3
WW_ratio_west	0.4	0.36	0.3
Shade_factor_north	0.5	0.5	0.5
Shade_factor_east	0.3	0.3	0.3
Shade_factor_south	0.3	0.3	0.3
Shade_factor_west	0.3	0.3	0.3
Buildingcode	2012	ENGIE	2012
Building Envelope	Medium	ENGIE	Light
Thermostat			
Tset_min	16	23	10
Tset_heating	21	23	18
Tset_cooling	24	24	50
Occupancy			
Schedual	7 to 17	Mon 3-19 tue to fri 6-19	Mon till fri 8 to 23
Ventilation			
Eff_HeatRecovery	0.7	0	0
ACH_Occu	3	1.7	4
ACH_Min	0.1	0.001	0.001
Generation			
P_heating	1.000.000 W	1.000.000 W	1.000.000 W
P_cooling	1.000.000 W	1.000.000 W	1.000.000 W
DH connection			
P_consumer	300.000 W	600.000 W	100.0000 W
Volume system	4 m^3	4 m^3	10 m^3

	Hotel 1	**Warehouse 2**	**Office 3**
Building			
L	30 m	100 m	50 m
B	30 m	200 m	25 m
H_floor	3.33 m	5 m	3 m
n_floors	12	1	4
Qi	15 W/m2	15 W/m2	30 W/m2
Plugload	20 W/m2	10 W/m2	15 W/m2
WW_ratio_north	0.5	0.2	0.5
WW_ratio_east	0.5	0.2	0.5
WW_ratio_south	0.5	0.2	0.5
WW_ratio_west	0.5	0.2	0.5
Shade_factor_north	0.5	0.5	0.5
Shade_factor_east	0.3	0.3	0.3
Shade_factor_south	0.3	0.3	0.3
Shade_factor_west	0.3	0.3	0.3
Buildingcode	2012	2012	2012
Building Envelope	Medium	Light	Medium
Thermostat			
Tset_min	21	10	14
Tset_heating	23	18	22
Tset_cooling	27	50	27
Occupancy			
Schedual	24/7	Mon till fri 8 to 23	9 to17
Ventilation			
Eff_HeatRecovery	0.5	0.7	0.5
ACH_Occu	2	1.7	2
ACH_Min	0.001	0.001	0.001
Generation			
P_heating	1.000.000 W	1.500.000 W	1.000.000 W
P_cooling	1.000.000 W	1.500.000 W	1.000.000 W
Heatpump			
power	500.0000 W	1.500.000 W	300.000 W

Appendix B – Wind turbine Enercon

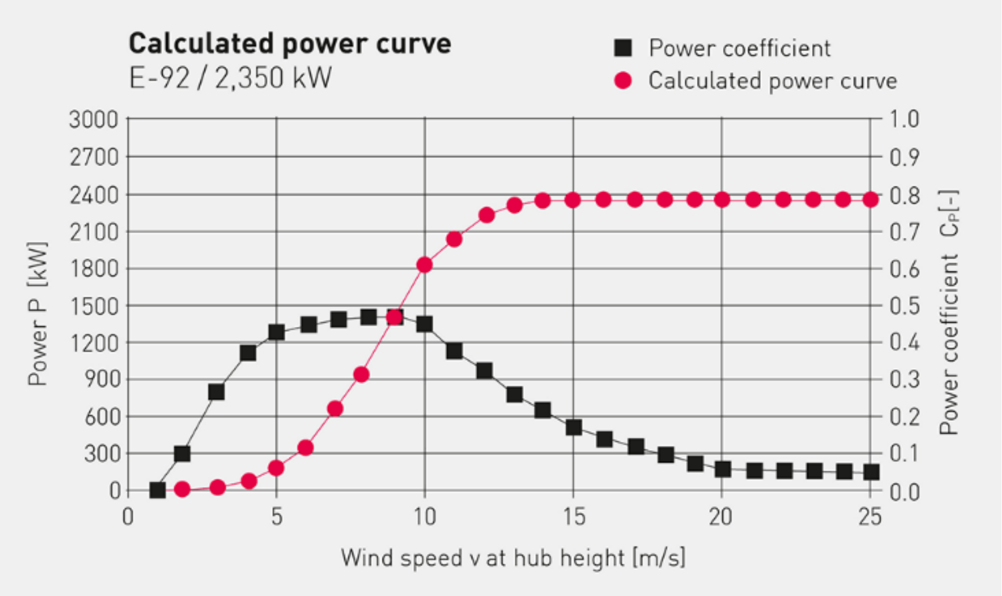

Figure 15 - Calculated power curve of the Enercon E-92 wind turbine

Appendix C – Validation

- Input parameters for the model of ENGIE zuidoost, for the calibration.

Area	L=20m B= 106m
H_floor	2.7 m
Qi	30 W/m2
AHC_Occu	1.7
AHC_min	0.001
Buildingcode	2003
Building Envelope	Medium
Occupancy Schedual	Mon 3-19 tue to fri 6-19
KNMI weather	Dec-2014 till Nov-2015 Maastricht
Shade N	0.5
Shade E	0.3
Shade S	0.3
Shade W	0.3
Tset_min	16°C
Tset_H	21°C
Tset_C	24°C
P_heat	340000 W
P_cool	500000 W
Heat recovery	Constant 20 °C air

Appendix D – Results Summer period

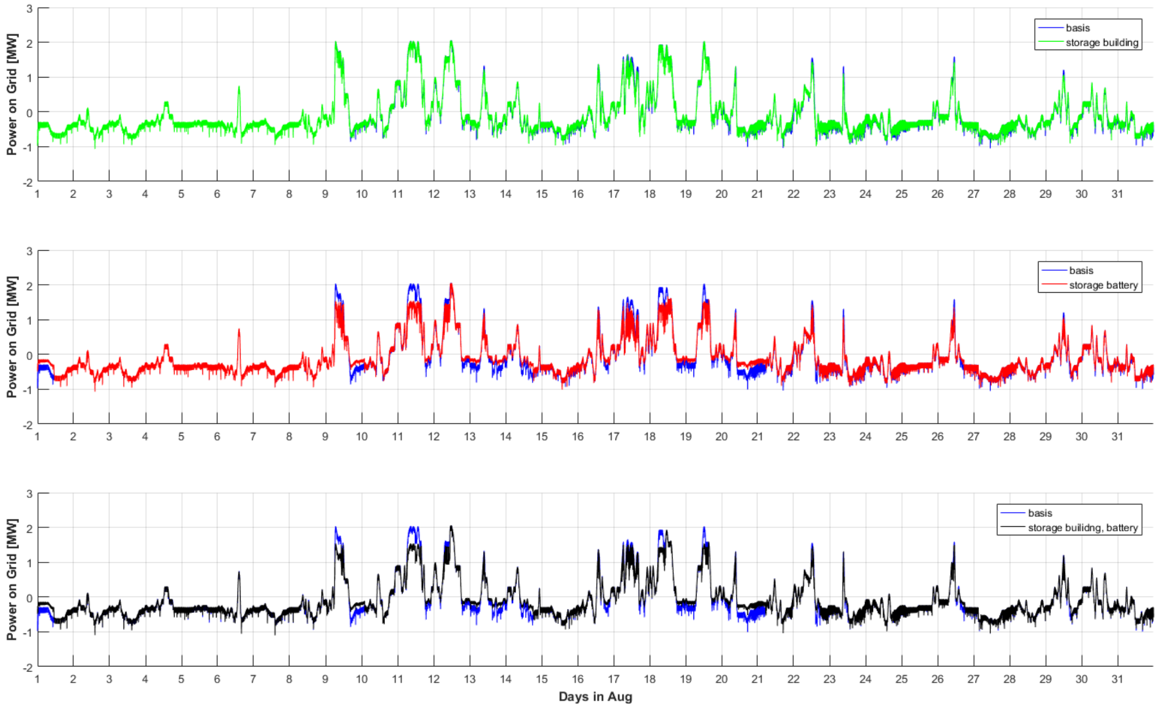

Figure 16 - Power fluctuation on grid connection for August (a) storage in building (b) storage in battery (c) storage in building and battery

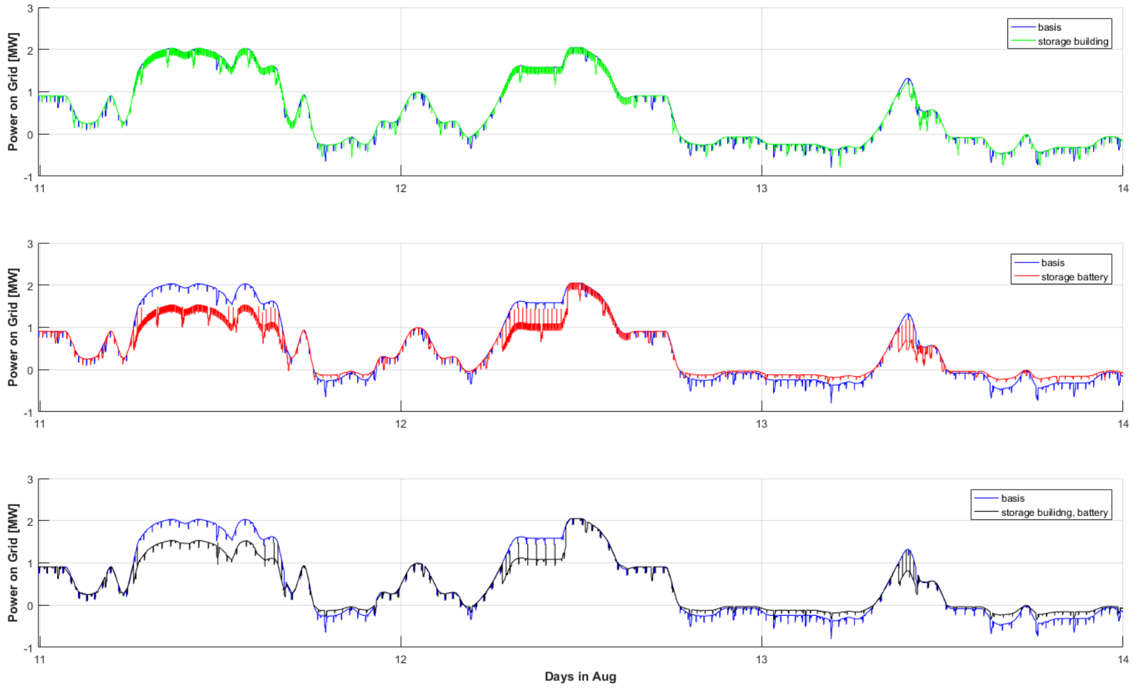

Figure 17 - Power fluctuation on grid connection for three days in August (a) storage in building (b) storage in battery (c) storage in building and battery

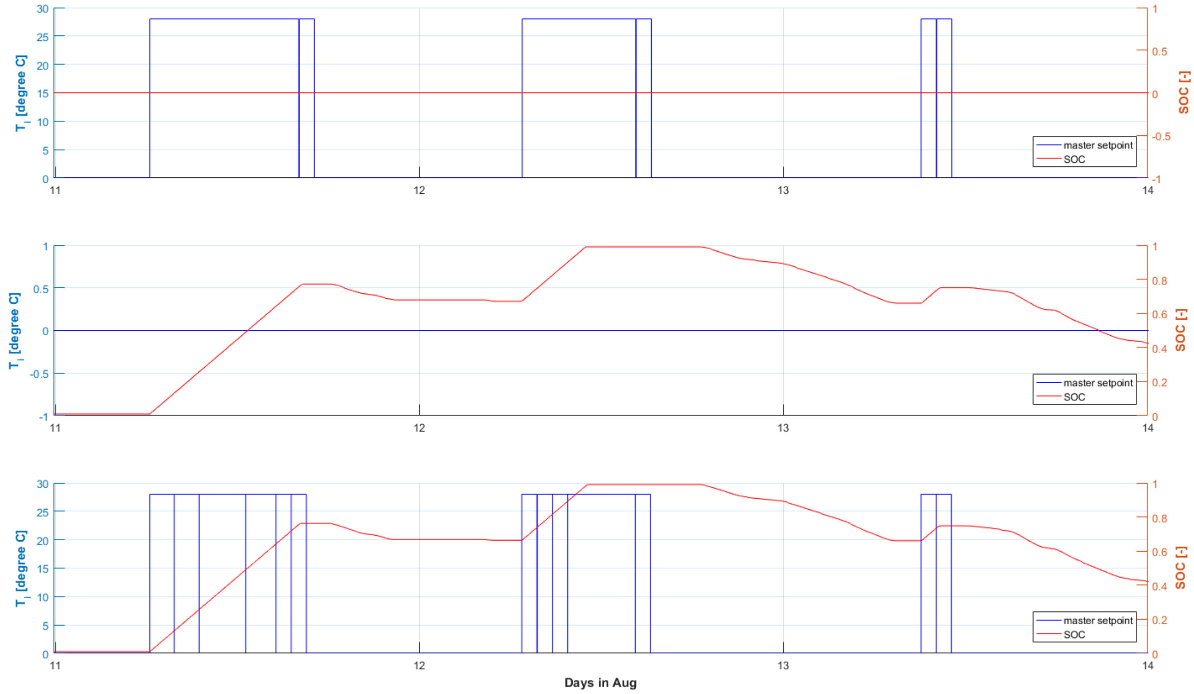

Figure 18 - Activated storage during three days in August (a) storage in building (b) storage in battery (c) storage in building and battery

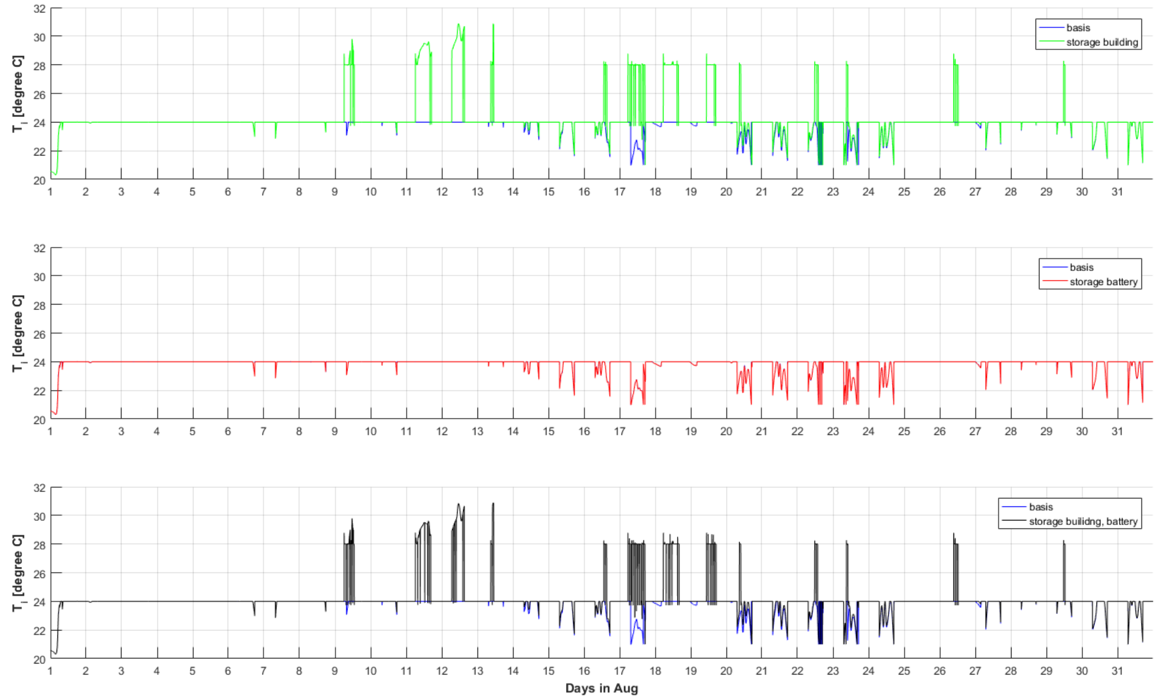

Figure 19 - Indoor temperature of office 1 in August (a) storage in building (b) storage in battery (c) storage in building and battery

Appendix E – Modelica Model A1 Deventer

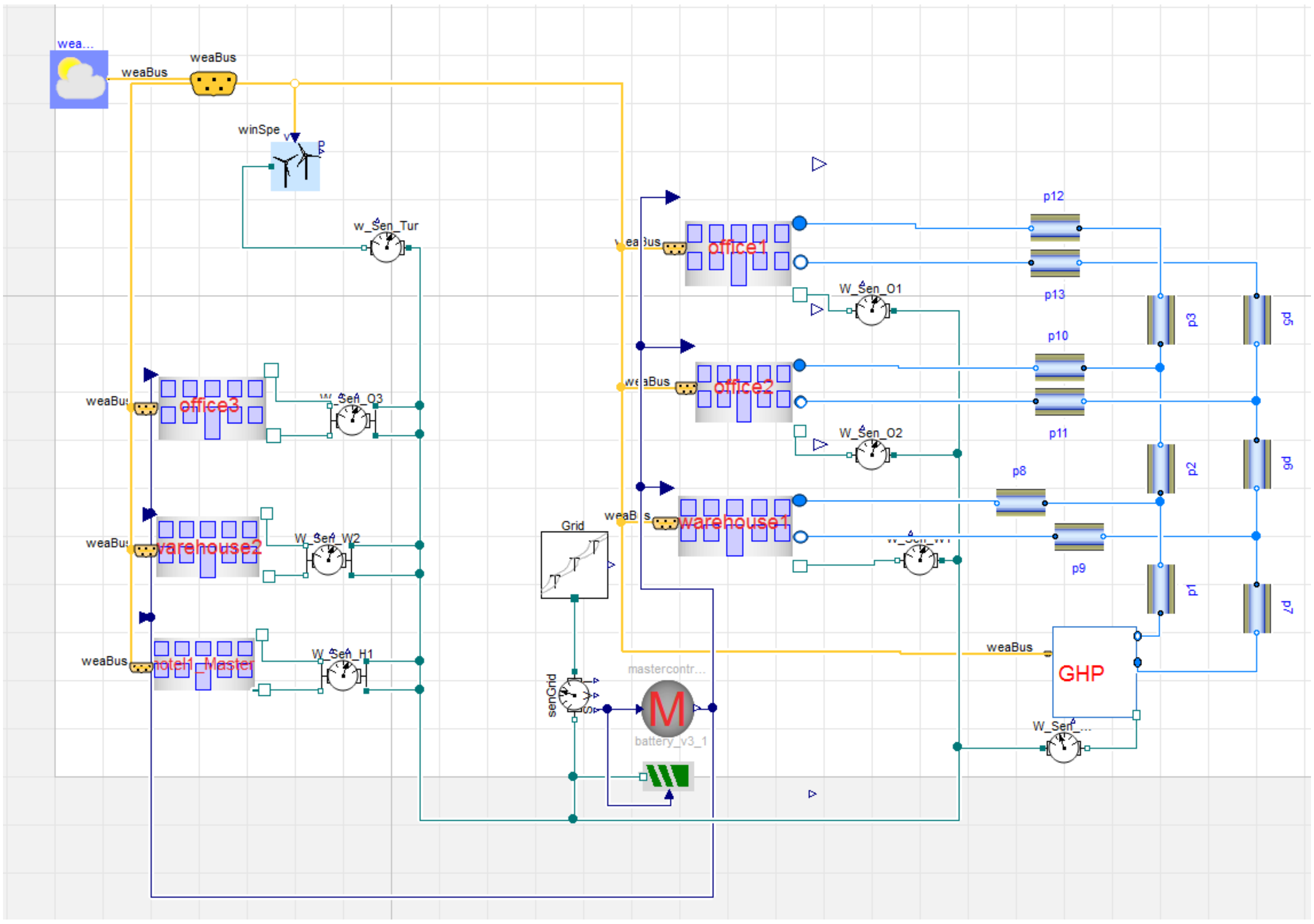

Figure 20 - Modelica model A1 deventer

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Where innovation starts

Reducing power peaks from renewable energy sources on the grid connection

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Summary

Electric energy produced by renewable energy sources, like wind power, have an intermittent production. During times of high electricity production not all the electricity might be consumed by the buildings demand. This surplus electricity from the generation introduce stress to the district grid, the transformer needs redeliver the electricity back to the public grid. To handle these peaks the grid infrastructure requires investments. Therefore, lowering the peaks could potentially reduce these investments. This could be achieved by storing the peak power on the district side before it is injected into the public grid.

In this paper, a case study is presented to evaluate the possibility of storing energy inside a business park to lower the power peak on the grid connection. The power on the grid connection is the power generated on-site minus the power demand from the buildings. Power peaks exceeding 1 MW need are stored on site. Because, if exceeded the grid infrastructure needs be changed and a bigger transformer is necessary. Storing in the district could be achieved by storing electricity in the “free” available thermal mass of the building, or by storing in an electric battery. Storing in the thermal mass will be conducted by increasing the heating set point of the building. The residual power peak is stored in a battery. Three storage scenarios are evaluated: storage in the thermal mass of the building, storage in the battery and a combination of storing in the thermal mass and the battery. The case study is a business park in an early-design phase. An initial outlook of the business park will be evaluated. The simulation models are made in Modelica to represent the buildings, wind turbine, heating generation and district heating network. The whole site is controlled by a master controller with the aim to reduce the peak loads.

Results of the simulation shows the most of the power peaks can be lowered by applying on-site storage in buildings and the battery. This results in a reduction of 81.3%, during winter, from the amount of power above 1 MW in comparison with no storage. This results in less stress on the grid connection and no need for larger capacity of the transformer.