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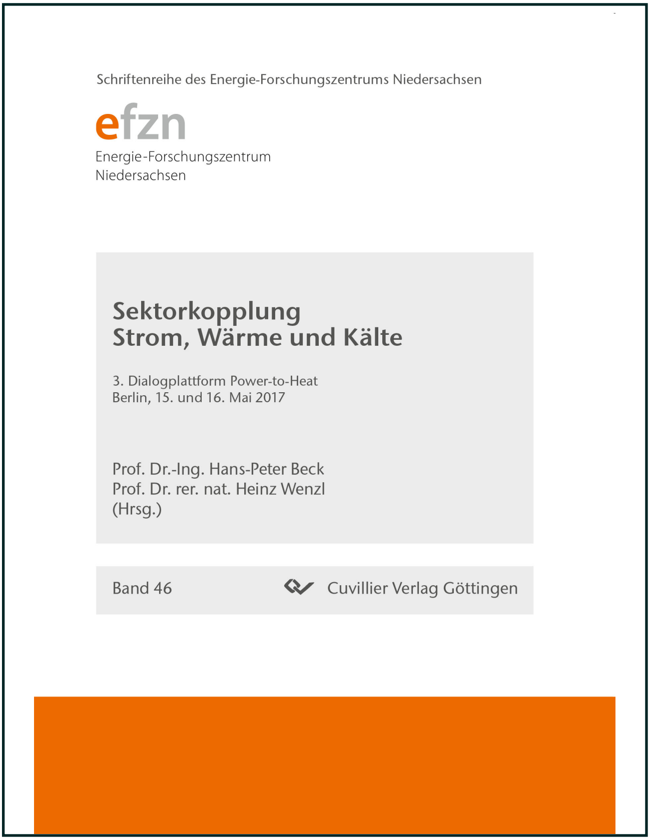
Sektorkopplung Strom, Wärme und Kälte

3. Dialogplattform Power-to-Heat Berlin, 15. und 16. Mai 2017



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1 Vorwort

Politisches Ziel und gesellschaftlicher Konsens ist, dass Photovoltaik- (PV) und Windkraftanlagen den größten Beitrag zur regenerativen Energieversorgung der Zukunft liefern sollen. Strom ist dann kein Veredelungsprodukt aus Kohle, Gas oder Nuklearbrennstoffen, sondern der primäre Energieträger, aus dem dann Veredelungsprodukte wie Gas oder flüssige Brennstoffe erzeugt werden können (Power to X). Es ist deshalb zu erwarten, dass die heutige Angabe von fossilen Energieträgern in Steinkohleäquivalente durch die Umrechnung in MWh oder GWh abgelöst werden wird. Strom wird also beim weiteren Ausbau der regenerativen Quellen der „Primärenergieträger“ der Zukunft sein.

Die unmittelbare Nutzung dieses Primärenergieträgers Strom ist zunächst technisch und wirtschaftlich sinnvoller als die Speicherung oder Veredelung zu anderen Energieträgern, weil Umwandlungsverluste und die Investitionskosten für die benötigten Anlagen vermieden werden können.

Für das jetzige Energieversorgungssystem mit den weitgehend getrennten Energiesektoren Strom, Gas, Wärme und Treibstoffe für den Verkehr ergeben sich daraus folgende Herausforderungen:

- Der Kraftwerkspark muss flexibilisiert werden, weil die Planungsgrundlage nicht mehr der gut prognostizierbare Lastverlauf sein wird, sondern der Residuallastgang, der nur sehr kurzfristig prognostizierbar ist. Kurze Anfahrzeiten, möglichst geringe Mindestlaufzeiten, viele Start-Stopp-Vorgänge und ein hoher Wirkungsgrad im Teillastbereich werden von den zukünftigen Kraftwerken gefordert. Der Rückgang der Jahresbetriebsstunden erzwingt niedrige Investitionskosten und geringe Fixkosten des Betriebs.
- Es wird Zeiten geben, in denen die Strommenge aus PV- und Windkraftanlagen den Strombedarf überschreitet. Dann stellt sich die Frage, wie dieser Überschuss verwertet werden kann. Bewertungskriterien für mögliche Lösungen sind das CO_2-Verminderungspotential und die Kosten zur Umsetzung von Lösungen mit Stromspeichern und Lastmanagement sowie die Nutzung von Strom für andere Anwendungsbereiche (z. B. Power-to-Heat) werden miteinander konkurrieren.
- In jedem Energieversorgungsystem gilt, dass das Angebot an Energie und die Nachfrage möglichst immer im Gleichgewicht stehen sollten, um den Speicherbedarf zu minimieren. Alle Speicher verursachen Energieverluste sowie Investitions- und Betriebskosten.
- Der Primärenergieträger Strom wird und muss in die Energiesektoren Wärme, Gas und Verkehr eindringen, um die CO_2-Minderungsziele einhalten zu können. Konnten in der Vergangenheit die Sektoren weitgehend getrennt be-

trachtet werden, so ist in der Zukunft eine sektorenübergreifende Betrachtung erforderlich.

Die Nutzung von Strom im Wärme- und Kältemarkt spielt dabei eine besondere Rolle, weil die erforderlichen Komponenten weitgehend kommerziell ausgereift sind, die Investitionskosten vergleichsweise gering sind und Wärme kostengünstig gespeichert werden kann, um zeitliche Differenzen zwischen Angebot und Nachfrage zu überbrücken. Die Systemeinbindung und die Entscheidung zwischen monovalenten Heizungen nur mit Strom und bivalenten Heizungssystemen, die Strom nur dann als Energiequelle nutzen, wenn Strom preiswert ist und dem witterungsabhängigen Dargebot von Strom aus PV- und Windkraftanlagen folgt, können nur dann erfolgen, wenn eine Wirtschaftlichkeit gegeben ist. Die Randbedingung dabei ist, dass der Komfort im Wohnbereich sowie die Produktion in Industriebetrieben nicht beeinträchtigt werden darf.

Dringender als technische und wirtschaftliche Fragestellungen müssen hierzu die regulatorischen und rechtlichen Fragestellungen gelöst werden. Ein Grundproblem dabei ist, dass die Energiewende, in der fossile Energieträger verdrängt und durch den neuen Primärenergieträger Strom abgelöst werden, fast ausschließlich von diesem über die EEG-Umlage finanziert wird. Bei betriebswirtschaftlichen Investitionen fällt deshalb häufig die Entscheidung gegen Strom und für Gas. Die Kosten für den Gasbezug inkl. aller Umlagen und Steuern sind zur Zeit signifikant geringer als die Belastung der Stromkosten durch die EEG-Umlage. Es drängt sich die Frage auf, warum gibt es keine Umsteuerung bei der Belastung von Kohle und Erdgas mit den Kosten zur Finanzierung der Energiewende?

Ohne eine energetische Gleichbehandlung mit Steuerungswirkung in Richtung des globalen Ziels 80 % Verminderung der Treibhausgasemissionen wird neuen notwendigen Flexibilitätsoptionen wie Power-to-Heat der Durchbruch verwehrt bleiben und das Potential zur Senkung der Kosten pro Tonne vermiedenen CO_2es nicht ausgeschöpft werden.

Die Beiträge in diesem Band und die Dialogplattforum dienen dazu, diese Diskussionen und die zur weiteren Umsetzung erforderlichen technischen Entwicklungen voranzubringen.

Prof. Dr.-Ing. H.-P. Beck   Prof. Dr. rer. nat. H. Wenzl

2 Conception and dynamic simulation of power-to-heat-plants for municipal services

A.Dillmann

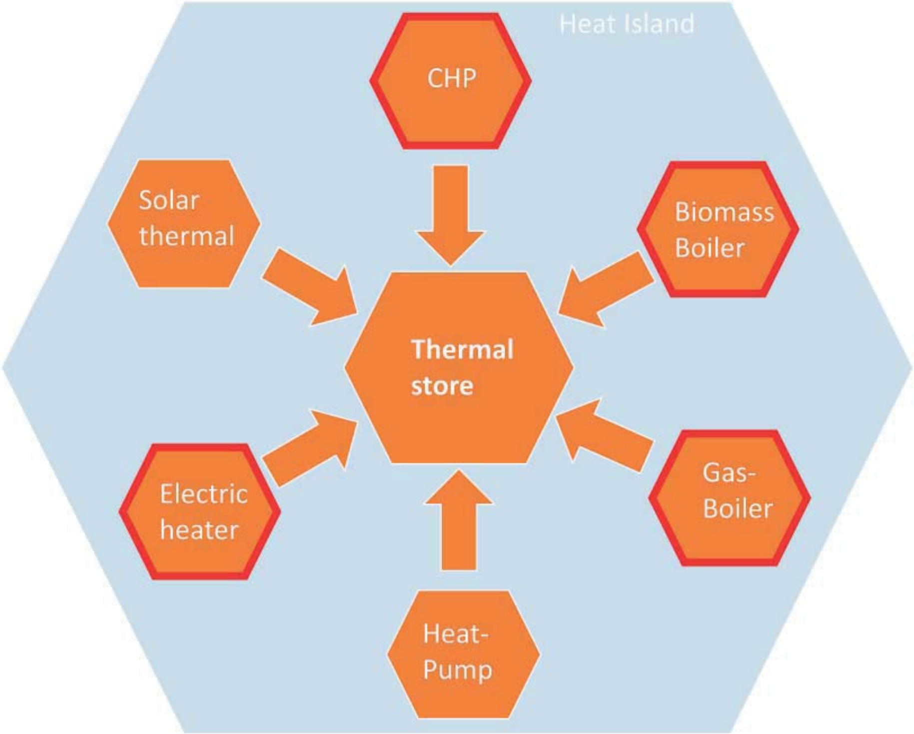
A new energy system shall be designed in collaboration between the research group energy systems and energy technology of the University of applied sciences Kempten (Allgäu) and the municipal services company of Bad Tölz. The project is called "designing of a heat island for the Bäderviertel in Bad Tölz". The energy system shall be able to produce and store thermal energy for district heating. The "Bäderviertel" is a combination of spa facilities, (single) apartment blocks and commerce and service businesses. There shall be also the possibility to convert electrical energy through a power-to-heat unit into thermal energy. This happens during times when the electric current at the power exchange is cheap or the price for current even is negative (negative residential loads).

In the first step an energy plant which consists of a power-to-heat unit, a gas boiler, a biomass boiler and a combined heat and power unit has been designed. All of the heat producers are connected to a storage which is functioning as a hydraulic switch between heat producers and heat consumers. The auxiliary energy is supplied by a regenerative photovoltaic system.

In this report the conception and the dynamic simulation of a power-to-heat plant for the municipal services of Bad Tölz is being described. First the sorted annual load curve of the heating demand and the dimensioning of the heat producers is being discussed. In the second step the duration periods of the electric heater during negative residential loads, the summed up energy amounts of the system and the use of regenerative and fossil fuels is described.

Design of a heat island for the Bäderviertel in Bad Tölz

The energy system is designed as a heat island. That means that various thermal heating producers, such as combined heat and power units (CHP), biomass boilers (BB), gas boilers (GB), electric heaters (EH), heat-pumps (HP) or solar collectors (SC) are combined to a storage. The aim is to create an extendable energy system for district heating.

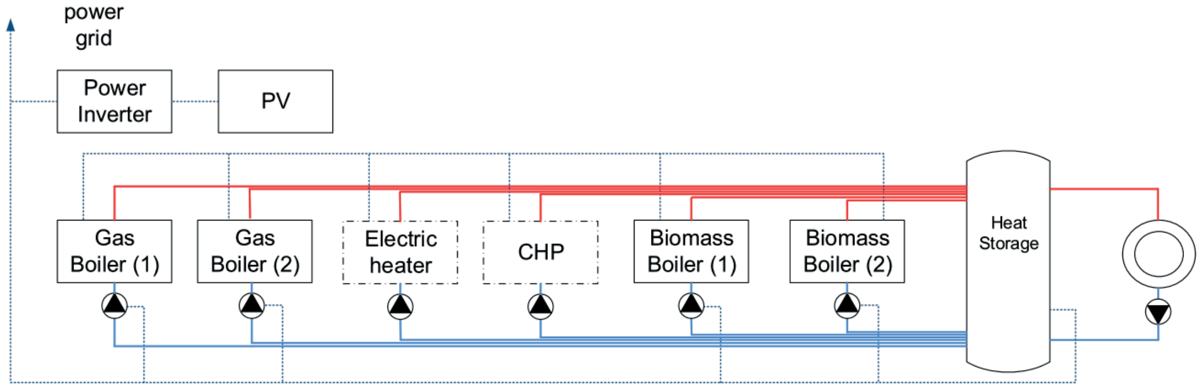


Pict. 1: Design of a heat island for the Bäderviertel in Bad Tölz

In the first step an energy plant which consists of a power-to-heat unit, a gas boiler, a biomass boiler and a combined heat and power unit has been designed. These heat producers are combined with a storage. The storage is charged to 85 °C by the combined heat and power unit and the biomass boiler. In order to have a reserve for the electric heater the storage can be charged to 95 °C by the electric heater only.

Preliminary considerations

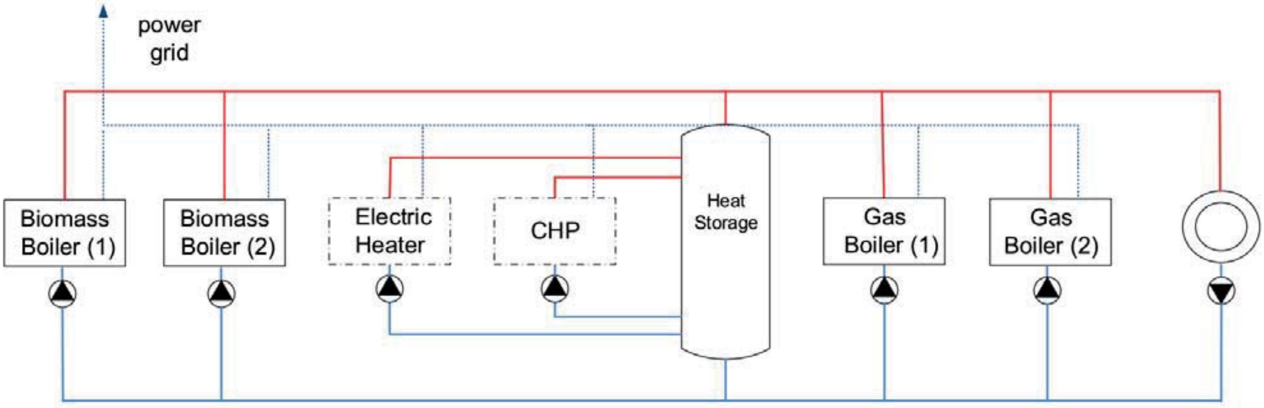
Before starting with the modelling process there were two preliminary considerations concerning the connection of the storage. In the first step a system that is based on the schematic drawing of Pict. 2 has been designed. In this concept all of the heat producers are connected to a storage which is functioning as a hydraulic switch between the heat producers and the heat consumers. The first advantage of a hydraulic switch is the free circulation of all the thermal energy streams and the hydraulic balancing of the whole system. In addition there is a good stratification of the hot water inside a hydraulic switch.



Pict. 2 Scheme of the modelled energy system. First phase of construction (solid line) second phase of construction (dashed line)

The auxiliary energy is supplied by a regenerative photovoltaic system or by the combined heat and power unit. For the first phase of construction a system which is consisting of two gas boilers and two biomass boilers has been modelled. For the second phase of construction, when profitable, the system can be extended by a power-to-heat unit or a line-commutated combined heat and power unit. Due to the line-commutated technology the combined heat and power unit is only operated when the price at the European Energy Exchange is higher than prime costs which include all the feed-in tariffs. The storage has been simulated with a size of 100 m^3 but it can also be bigger. The pressure within the whole system is 3 Bar. The inlet temperature to the suppliers shall be 80 °C because of the building topology and because of the heat losses of the district heating. The heat consumption is 21,038 GWh/a. The heat losses are 1,764 GWh/a. The maximum heating power is 8,35 MW. However the gas boilers are designed to a maximum heating power up to 14 MW in order to be able to achieve supply security on exceptional cold days as well

Concerning the biomass boilers there are two controlling concepts. In a seasonal controlling concept the biomass boilers modulate between 3/3 of the nominal heating power in winter and 1/3 of the nominal heating power in summer. In the reported simulation model the biomass boilers modulate flexible between 1/3 and 3/3 of the nominal heating power. The first biomass boiler however is prioritized. The second biomass boiler therefore is only operated when the heating power demand is transcending the heating power of the first biomass boiler. During the operation of the biomass boilers also the duration periods of the emergency cooler is documented. The emergency cooler is operated when the heating power of one of the biomass boilers is transcending the heating power of the heating power demand of the consumers. The combined heat and power unit is not modulating. The switching on and off process of the combined heat and power unit is limited to one switching on and off process per hour. The gas boilers are modulating between 30 % and 100 %. The first gas boiler is prioritized. The power to heat unit is only operated during negative residential loads. The negative residential loads refer to the European Energy Exchange.



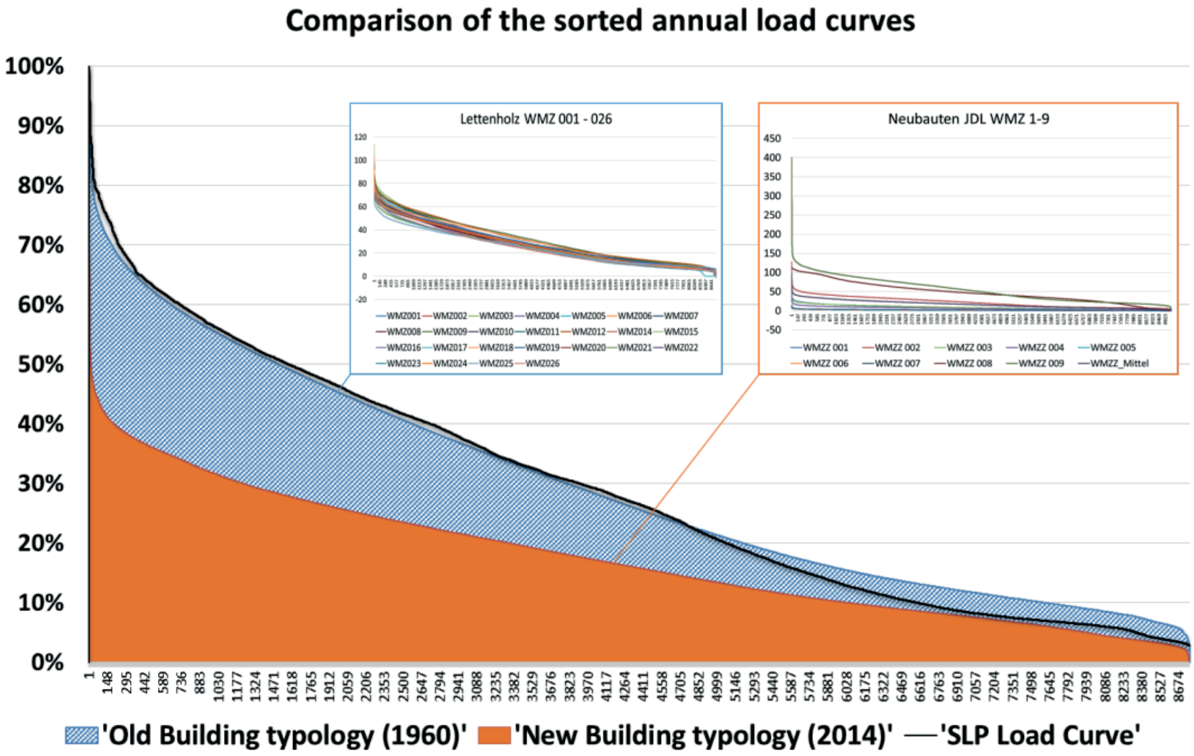
Pict. 3 Variant to the modelled energy system. First phase of construction (solid line) second phase of construction (dashed line)

A variant to the first concept is the second concept (Pict. 3). In the second concept the storage is integrated independently. The peak loads are produced by the two gas boilers which are behind the storage. The power-to-heat unit and the combined heat and power unit are still directly connected to the storage. The biomass boilers are directly connected to the district heating. With this interconnection the volume flows of the biomass boilers do not intermix the stratification of the hot water inside the storage. The surplus thermal energy is fed into the storage.

Determination of the consumed heating power

First the sorted annual load curves of the heating demand have been measured. Therefore the heat meters of a consisting heating district in Bad Tölz have been evaluated. There is a load curve of the heating demand for each typology of building. In the next step the measured load curves have been matched with the standard load profiles from the standard load profile procedure. [1] After that it was possible to transmit the building typology of the existing heat district to the new heat district “Bäderviertel”.

Pict. 4 shows the peak loads of the heating demand of new buildings (2014) in comparison with old buildings (1960) within the “Bäderviertel”. The peak loads of the new buildings are relatively higher than the peak loads of the old ones due to exceptional cold days in winter where additional heating is necessary. Generally new buildings have higher thermal insulation because of the German Energy Saving Regulation (EnEV). The losses of circulation and water heating run parallel. As the orange curve shows, the heating demand of the new buildings is lower because of smaller primary energy requirements due to energy saving regulations.

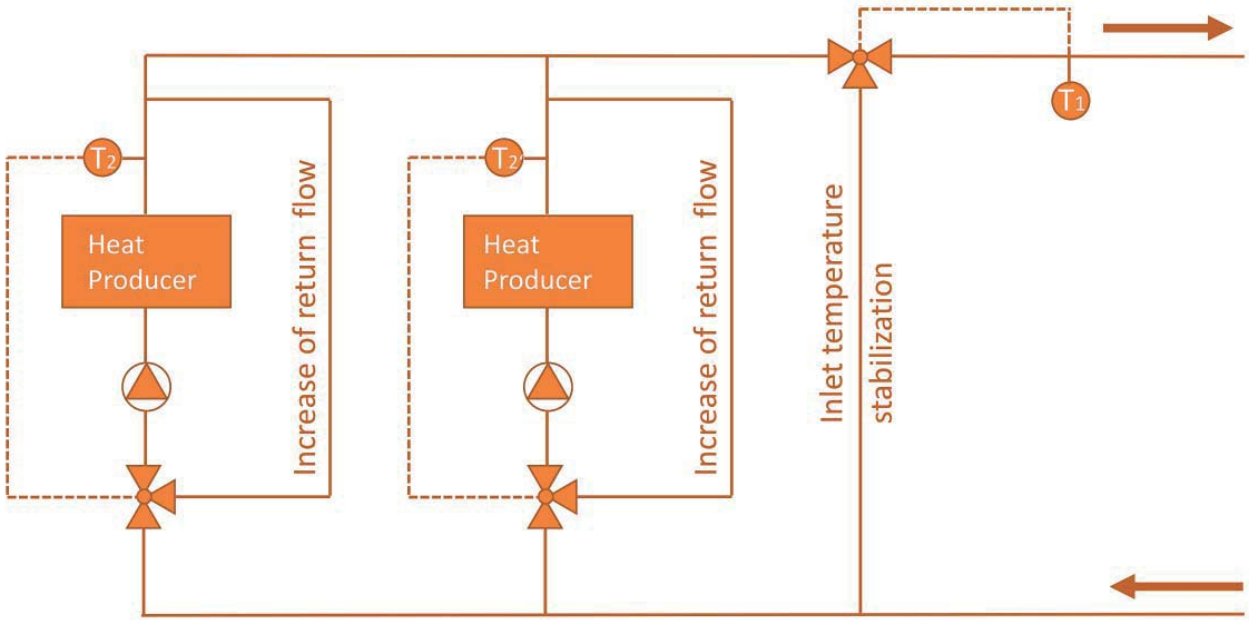


Pict. 4 Sorted annual load curves of old buildings (1960) and of new buildings (2014)

Modelling of the energy system

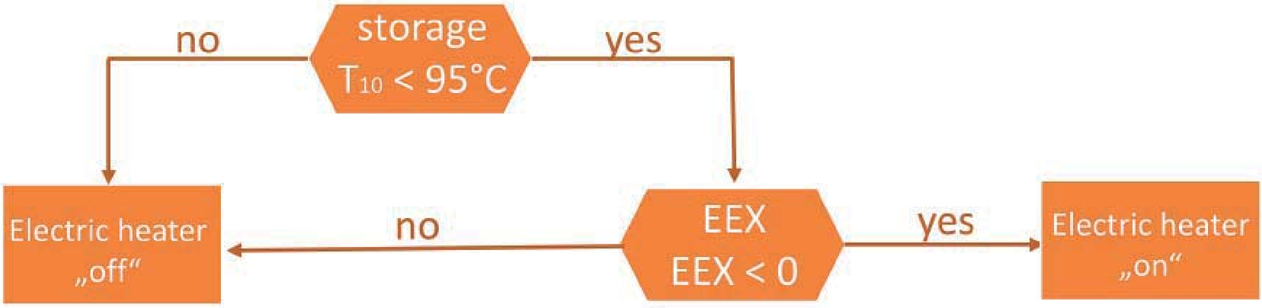
For the modelling and simulation of the energy system the simulation environment Matlab-Simulink has been used. Simulink allows an easy graphical integration of mathematical modules within a hierarchic architecture. For all the basic modelling there are a number of continuous and discrete modules available. Simulink also can be extended by so called blocksets. Parts of the modelled energy system have been designed by the Carnot-Toolset, which is freely available at the Solar Institute Jülich [2]. The Solar Institute Jülich belongs to the University of applied sciences of Aachen (Germany). There are existing various programmed Simulink modules for thermo-hydraulic calculations within the Carnot library.

By the application of an inlet temperature stabilization constant temperatures in all heating circuits are realized. Depending on the inlet temperature T1 part of the cold volume flow is added in order to have constant outlet temperatures. In the inlet of each component is a three-way valve which increases the return flow to the temperature T2 as long as the component is not providing full power. This hydraulic control guarantees that there is a stable temperature T1 at any time.



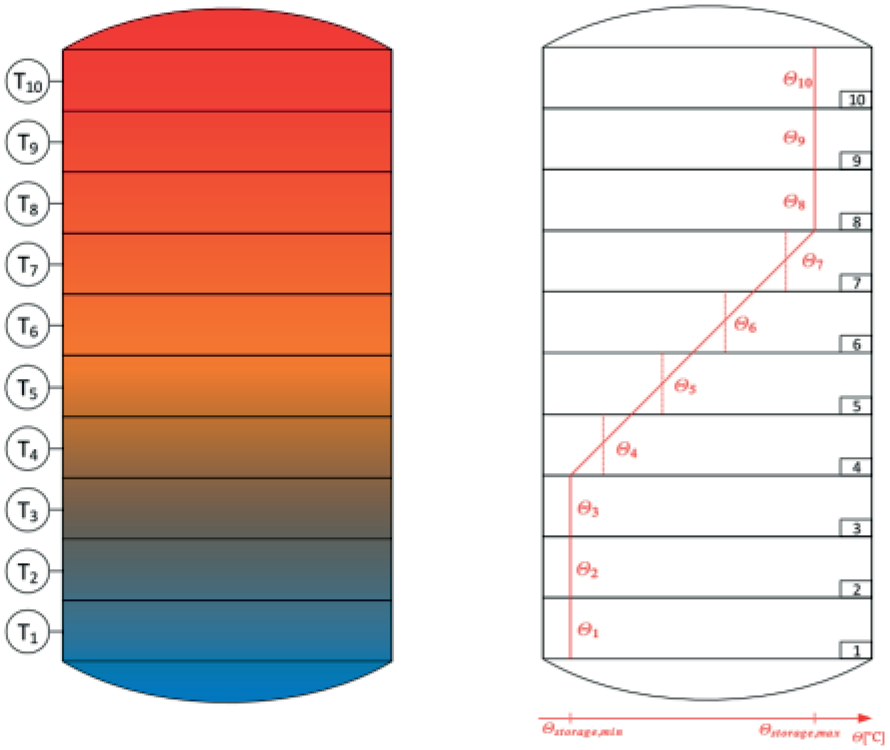
Pict. 5 Increase of return flow and inlet temperature stabilization within the modelled energy system

The control strategy of the power-to-heat unit differs to the control strategy of the other components. This is because it is depending on the prize from the electric current at the power exchange. The electric heater is operated when the electric current at the power exchange is cheap or the price for current is even negative. In order to be able to operate the power-to-heat unit at any time it is necessary to have a reserve for the electric heater in the storage. As a reserve for the electric heater is needed, the storage can be charged to 95 °C by the electric heater at any time. The other components, like the biomass boilers, charge the storage to 85 °C. The electric heater shall be operated in full load in order to provide as much control energy as possible.



Pict. 6 Simplified control scheme of the electric heater

There are ten temperature sensors installed in the storage. These temperature sensors (in Carnot they are called nodes) monitor the stratification of the hot water. A controller is coupled with the ten temperature sensors. The controller regulates all the heat producing components so that there is no overcharging of the storage. If temperature increases above 85 °C the controller switches of the heat producer which is connected to a certain temperature sensor. With a constant temperature of the storage of 85 °C it is secured that enough heating power is provided for the district heating. The inlet flow to the Consumers is 80 °C.



Pict. 7 Location of the sensors and temperature profile inside the thermal storage [3]

The mass flow of the pumps is variable in order to adapt the heating power exactly to the heating demand. Before the operation of the heat producer a volume flow sensor verifies if there is a sufficient circulation. So it is secured that the produced heat is sufficiently removed. In a second step the firing can be started or the power-to-heat unit can be initialized. In addition there is a variation of the mass flow at the consumer pump. The mass flow of the consumer pump is proportional to the heating power demand. If there is high heating power demand the mass flow to the thermal store is high. If there is low heating power demand the mass flow to the thermal store is low. This controlling strategy guarantees the delta T at the consumers is constant.

First simulation results

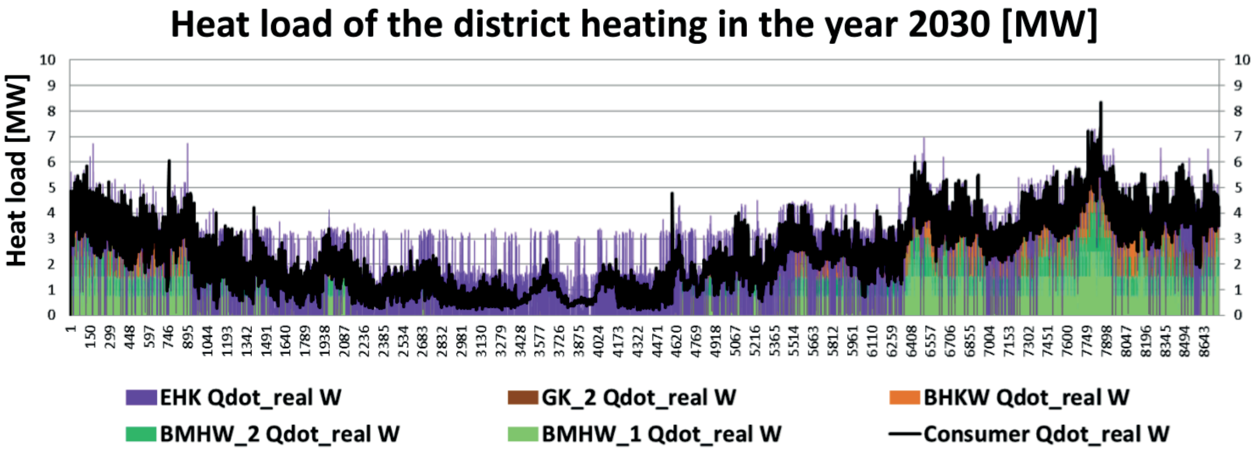
In this simulation a variation of the European Energy Exchange prize is done in order to get a statement about the profitability for the next 13 years. The dimensioning of the components stays the same. The effects of a varying European Energy Exchange prize shall be presented in the following presentation of the first simulation results.

Tab. 1 Amount of negative residential loads (own guess)

	2014	2017	2020	2023	2026	2030
Amount of negative residential loads in [h] (own estimate)	64	132	252	672	1096	1857

One scenario which considers the development of the negative residential loads has been published by the Bundesverband für Erneuerbare Energien (BEE) [4]. Within the report scenarios for the years 2012, 2020 and 2030 have been considered. In the year 2012 all of the renewable energy production could be assimilated by the power grid. In 2020 up to 2030 there are larger periods with negative residential loads. In all scenarios it becomes apparent that the maximum residential load is only slowly decreasing during the years, whereas the minimum residential load decreases fast. The renewable energies therefore only decrease the minimum residential loads. But still times where there is a surplus on electrical energy are increasing. Therefore flexible instruments like power-to-heat become essential.

Pict. 8 shows a simulation of a power-to-heat unit, a gas boiler, a combined heat and power unit and two biomass boilers in 2030 according to an own estimate (Tab.1). The heat load of the district heating is shown as well. There are shorter periods where the combined heat and power unit is running and larger periods, especially in summer, where the heating is done by the power-to-heat unit.



Pict. 8 Heat load of the district heating in the year 2030 per hour

In Pict. 9 the runtimes of the heat producers in the years 2014, 2020 and 2030 are shown. In all three simulations the configuration of the energy system doesn't