Gas driven cogeneration network systems as impetus for an intelligent and dynamic grid and the development of renewable energies

Main author
Stefan Storace
Research & Development
LichtBlick AG, Hamburg – Germany
Stefan.Storace@LichtBlick.de
Co author
Gerhard Schmitz
Institute of Thermo – Fluid Dynamics, Applied Thermodynamics
Hamburg University of Technology
Germany

1. Abstract

Most of the world wide electric energy demand is generated by the use of fossil resources in central large-scale power plants. With the global increasing energy requirement and at the same time decreasing energy resources sustainable alternatives to the conventional energy supply will become necessary. Not at last also because of the rising air- and climate stressing emissions. An important step in this interrelation to achieve an enduring electrical power supply is the development of a flexible and smart grid in order to allow the integration of a high contingent of renewable energies. The reason for the necessity of a dynamic grid lies therefore in the volatility of the availability of for example hard predictable wind or solar energy. In the same way it is important to increase the energy efficiency of future power plants using fossil resources compared to today's facilities. A concept, which allows the realisation of both requirements, is the combined generation of electricity and heat in local gas driven cogeneration units, installed in single – or multi – family houses. Whereas the single units are connected and controlled via a centralised data connection to a highly dynamic and efficient virtual power plant in order to generate global synergy effects of this local constellation of the units. At this connection the heat product of the combustion process can be used directly on location while the generated electricity can be feed synchronised into the public grid. With this on the one hand the overall efficiency of the cogeneration unit lies at around 90% and on the other hand the localisation of the units with its very short start-up phases enables to establish a highly dynamic grid where the electricity is generated swarm – like during times of high demands in respectively specific regions.

The research activities in this interrelation supported by LichtBlick, a German supplier of electric energy and natural gas in cooperation with the Institute of Thermo – Fluid Dynamics of the Hamburg University of Technology refer to the analysis, simulation and evaluation of gas driven cogeneration units centrally controlled within a virtual power plant. The subject – matter is the analysis of the system requirements of a cogeneration system under economical and environmental boundary conditions. To reproduce the complexity of the different influencing factors from the technical characteristics of the single unit up to the global energy economics a dynamic simulation environment is applied which allows to establish thermal, electrical as well as economical models. The results of the examinations are therefore based on the simulation language Modelica, whereas all developed models were calibrated with experimental data from corresponding manufactures. They show the optimal dimensioning of the cogeneration unit itself as well as the dimensioning of the necessary buffer storage in order to uncouple the generation of electricity from the heat demand of the examined building. Based on this holistically consideration and the aim to make accessible a high potential of customers by minimising the footprint of the cogeneration system technological alternatives to the commonly used water buffer storage, like the latent heat buffer storage are compared in order to evaluate the feasibility of a volume reduction without a loss of capacity or performance. As a further possibility to uncouple the electricity generation from the heat demand and in the course of an integral local energy supply different concepts for the usage of an additional electro chemic storage in interconnection with a cogeneration unit and a heat buffer storage are demonstrated, too.

Contents

2. Introduction

Cogeneration units are used since a long time to locally generate electricity while using the thermal heat. Its operation is predominantly conform with the heat requirement of the building whereat the current generation is inferior. Typically the aim is to use most possible of the produced electricity directly on location because the feed into the public grid normally is less lucrative. Not at last this is based on the stochastic operation and the relatively low electrical power of a single unit. For the current feed into the public grid thereby is merely paid a small amount for the so called base load current. Via a centralised control of every single cogeneration unit though it gets possible to generate synchronous operating times and with this in summation a high overall power in defined points in time. This structure is also called a virtual power plant. In this case of a systematic supply of the cumulated electrical power, new and higher commercial yields using alternative remuneration models are available. At this in detail the remuneration potential at the so called spot market in Paris (EPEX) is analysed and compared to the conventional remuneration of the produced current.

Based on an analysis of the available technologies for the examined main components of a cogeneration system like cogeneration unit, buffer storage and battery the core of the research is a dynamic simulation of the single components interacting together within a virtual power plant. To represent the dynamic characteristics and the complex interrelations within the examined thermic, electric and economical influencing factors and in order to optimise the cogeneration system concerning the dimensioning of the single components and the operation mode the simulation language Modelica is used. Figure 1 gives an overview of the interdependences of the examined components. At this all developed models were calibrated with experimental data from corresponding manufactures.

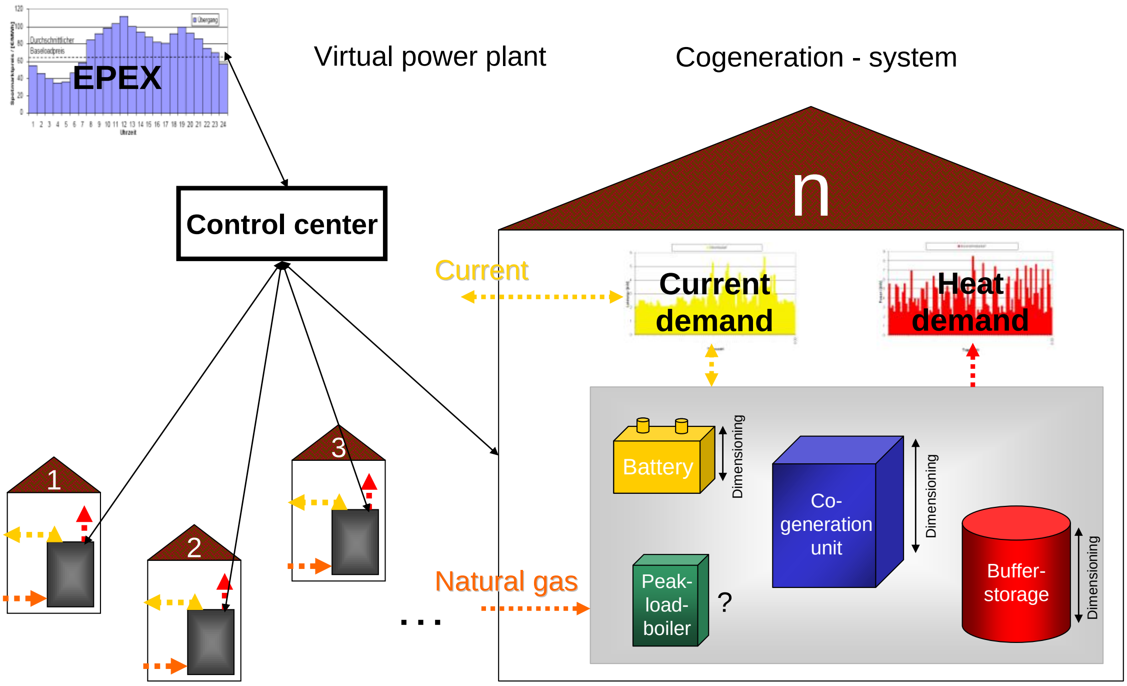

Figure 1: Overview of the interdependences of the examined components in the virtual power plant

The economical reflection gives a comparison between the common remuneration for a cogeneration unit in Germany, the remuneration potential within a centrally controlled virtual power plant and a conventional energy supply via a high efficient central gas and steam power plant for the current production in combination with a boiler for the heat supply of the multi – family house. Within the network of the virtual power plant also the profitability of an alternative buffer storage technology as well as of an additional chemical battery is shown.

3. Scaling of the components of a cogeneration system within a virtual power plant

Elementary for a representative modelling of a cogeneration system is the choice of realistic boundary conditions. For the examined case resilient data for heat requirement, warm water, and current demand of the considered building as well as data of the spot market are primarily necessary. Therefore on the side of the building thermal and electrical norm profiles from the VDI – guideline 4655 (Figure 2) and on the side of the spot market empirical data from the EPEX in Paris / EEX in Leipzig (Figure 3) as well as prognosticated data form LichtBlick are used in order to build the base of a one year simulation.

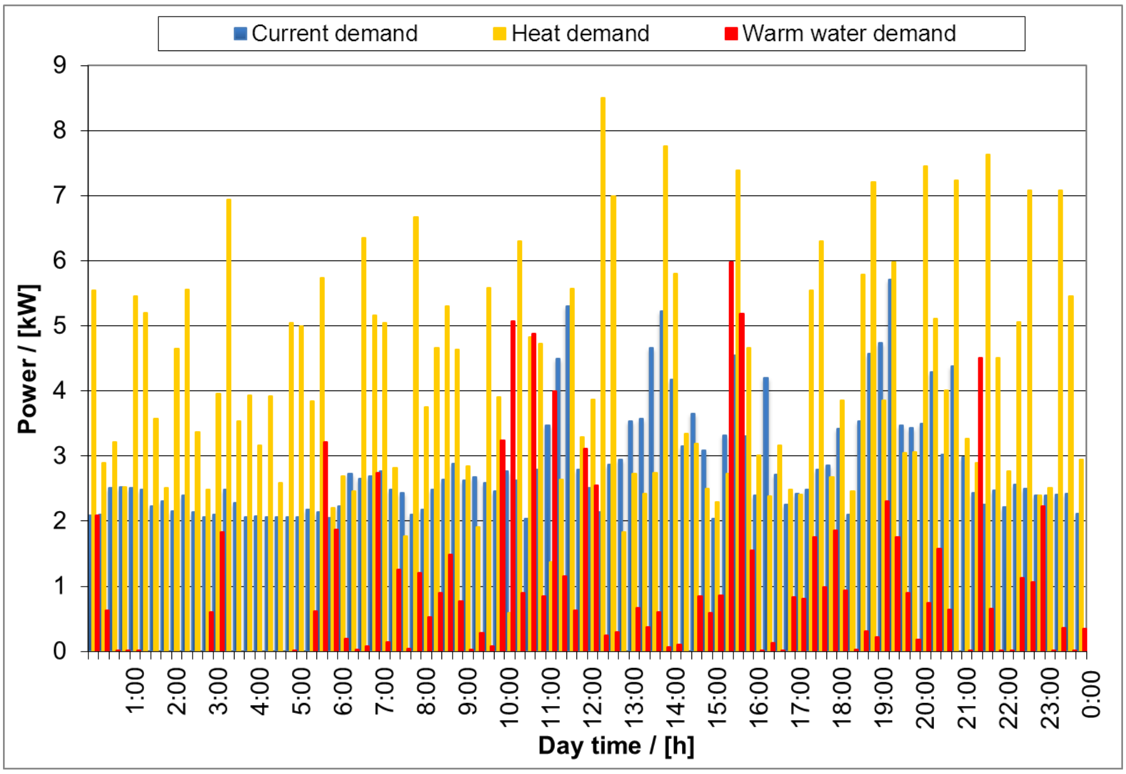

Figure 2: Example of thermal and current profiles of an 8 flat multi – family house with an annual thermal heat demand of 65000 kWh referred to the VDI guideline 4655 [VD1]

To compare the remuneration potential of a virtual power plant at the spot market with the conventional remuneration of the local produced current of a cogeneration unit the respective effects are analysed and compared on the level of one single building. In this case the simulated models equate to a multi – family house with an annual heat requirement of 65.000kWh. On the basis of the reference building exemplarily design criteria in dependency of the remuneration model are defined for the cogeneration system whereat the influence of the dimensioning of buffer storage, cogeneration unit and battery is analysed.

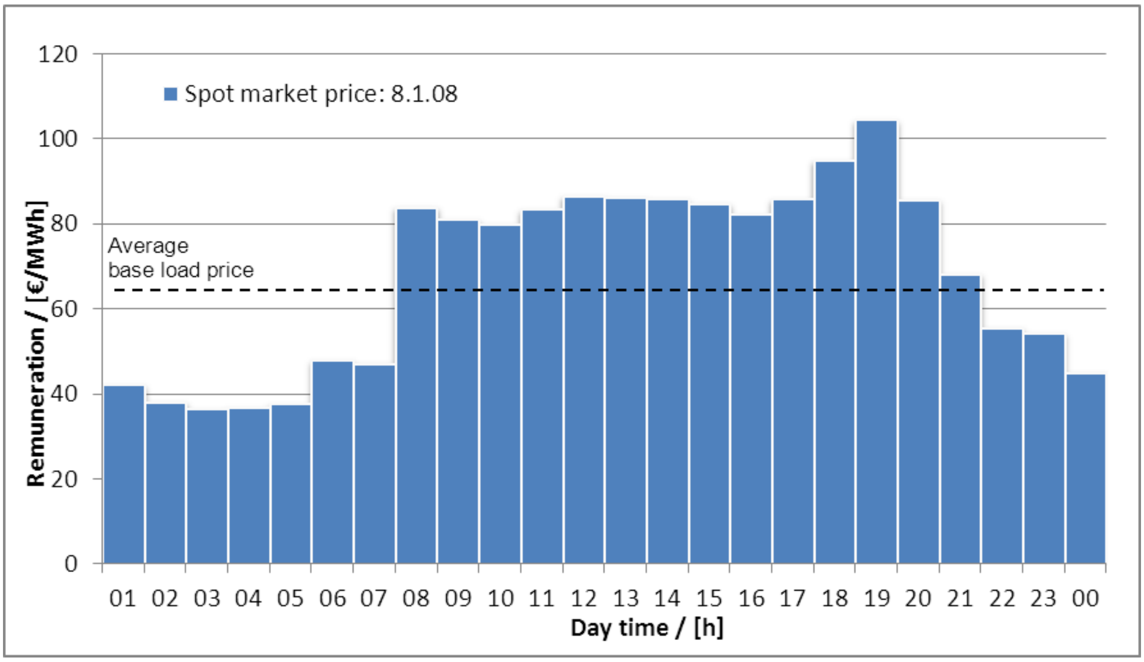

Figure 3: Development of the spot market price at the 8.1.08 over the average base load price of the first 6 month in 2008 [LB1], [EE1]

3.1. Cogeneration unit – Buffer storage – Peak load boiler

To describe the influence of the power of a cogeneration unit two engine – power classes within a range from 5 and 20 kW_{el} are considered. The developed models are orientated to at the market available products. Table 1 gives an overview of its performances.

Table 1: Abstract of the data sheets for the simulated cogeneration units [SE1], [PP1], [BU1]

Manufacturer		SenerTec	Power Plus Technologies	Buderus
Type		Dachs	Ecopower (modulating)	Loganova E0204 MN-20
Fuel	-	Natural gas	Natural gas	Natural gas
Functional principle	-	Otto-engine	Otto-engine	Otto-engine
Electrical power	kW	5,5	1,3 - 4,7	18
Thermal power	kW	12,5	4 - 12,5	32
Fuel power	kW	20,5	5,9 - 19	54
Max. flow temperature	°C	83	75	85
Max. return flow temperature	°C	70	60	75
Empty weight	kg	530	395	900
Liquid capacity	kg	5	5	-
Efficiency: Electric	-	0,27	ca. 0,25	0,33
Thermic	-	0,61	ca. 0,65	0,59
Overall	-	0,88	0,9	0,92

By dint of a long term simulation of the examined multi – family house within the described ecological boundary conditions a technical – economical accord of the analysed systems based on the particular remuneration models become possible. Figure 4 gives a closer overview of the technical interconnections of the single components of the examined cogeneration systems on the level of one building.

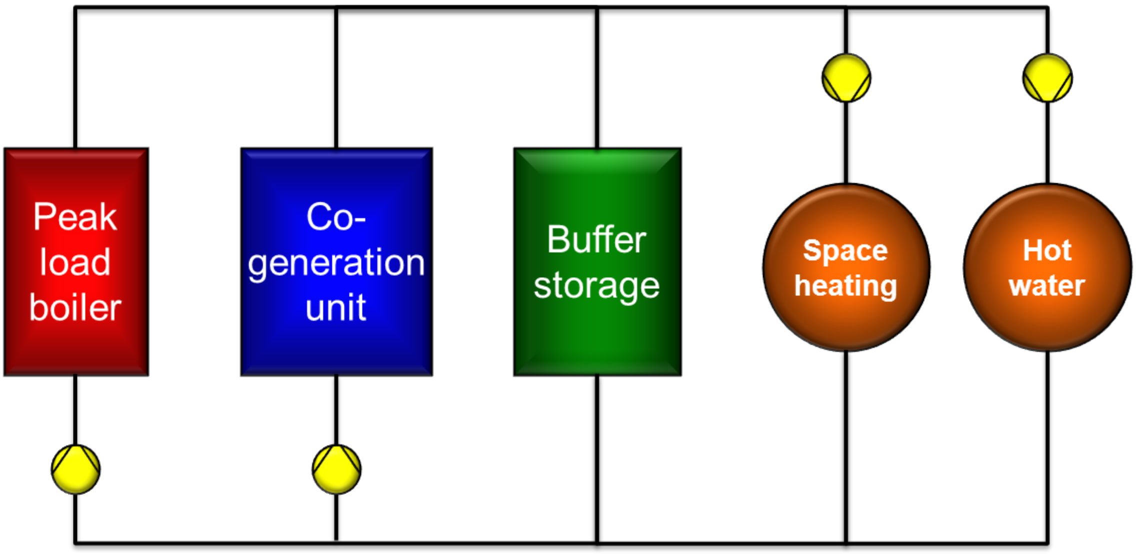

Figure 4: Overview of the technical interconnections of the single components of the examined cogeneration systems on the level of one building

It turns out that the optimal dimensioning of the buffer storage within a cogeneration system elementary is depending on the engine – power class of the unit. According to experience long clock cycles and a minimum operating time of one hour should be warranted. In connection with a virtual power plant and a centralised control of the unit the additional requirement of a time optimised operation mode has to be taken into account. From that follows the necessary consequence of an optimal decoupling of heat- and current- supply. In Figure 5 is shown the quantitative influence of the buffer storage size on the contribution margin in dependence of the remuneration model.

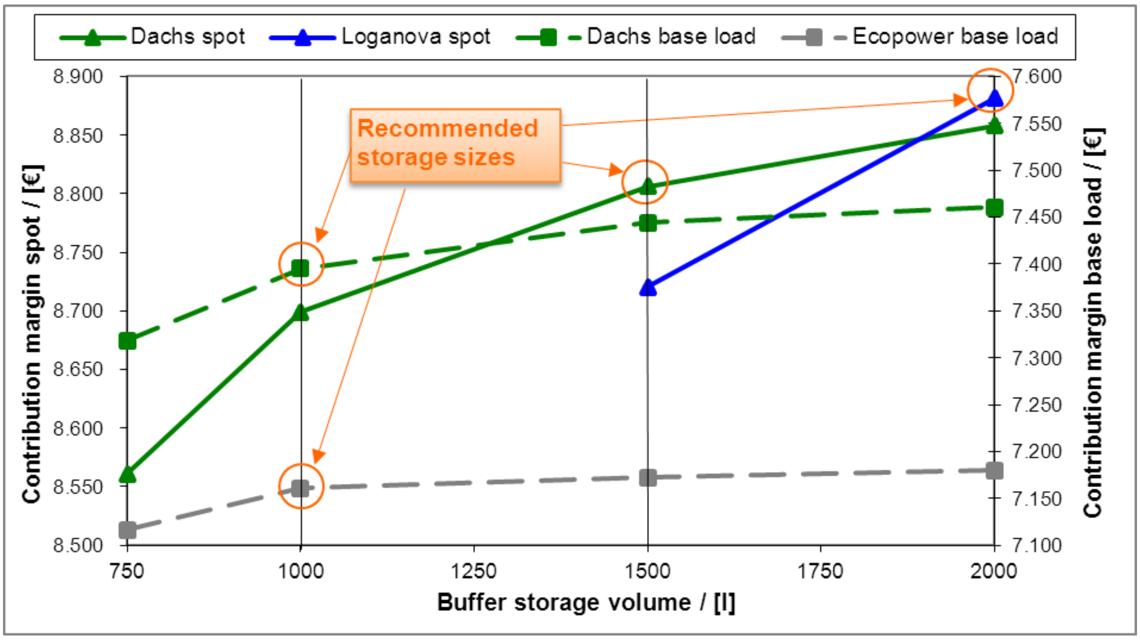

Figure 5: Quantitative influence of the buffer storage volume to the annual financial net cash flow for the remuneration at the spot market and the remuneration according to the common base load price for the year 2008

For the remuneration according to the base load price the units Dachs and Ecopower in the $5kW_{el}$ range achieve good results with a 1000l buffer storage. The advantage compared to the 750l storage is primarily based on a minor usage of the peak load boiler which normally constrains the potential current production with every operation. With storages major than 1000l the operating times of the boiler are almost reduced that far, that a further augmentation of the volume has no noteworthy effect on occurring thermal peak demands. Furthermore the higher potential of decoupling the heat- and current- supply has nearly no more positive impact to the clock cycles of the unit. The comparison of the two units illustrates the advantage of a relative high electrical efficiency (compare Table 1).

In case the cogeneration system with the Dachs shall participate at the spot market, up to a storage volume of 1500l a relevant additional benefit can be generated. The Loganova unit in the $20kW_{el}$ range here shows a clearly minor value with 1500l respect to the earnings with the 2000l storage which is founded in an inappropriate clock performance. Based on the high power of the Loganova and its comparatively high electric efficiency the produced electricity is only used in a slight way for the own usage of the building. It can be used especially to cut the peak load at the spot market. But only a bigger storage of 2000l allows to unfold the potentials of a high electric power and efficiency respect to a smaller unit in the $5kW_{el}$ range by an adequate uncoupling of heat- and current- supply. Special advantage of the powerful Loganova is moreover the saving of a peak load boiler so that the complete heat demand of the building can be supplied via the cogeneration unit. Compared to the usage of a monovalent gas boiler the annual contribution margins of every considered remuneration models are more than two times more profitable.

3.2. Alternative storage technologies

In order to make technically accessible a high potential of customers it is important to minimise the footprint of the cogeneration system. Especially the buffer storages with in the examined case are up to 2000l per unit are requiring a huge footprint. In this case technological alternatives to the commonly used water buffer storage, like the latent heat buffer storage are getting interesting in order to evaluate the feasibility of a volume reduction without a loss of capacity or performance.

As a further possibility to uncouple the electricity generation from the heat demand and in the course of an integral local energy supply different concepts for the usage of an additional electro chemic storage in interconnection with a cogeneration unit and a heat buffer storage have been analysed. In this paper exemplarily one of the possible economic integration options is shown.

3.2.1. Latent buffer storage

Important parameters within a benchmark of alternative storage technologies are the capacity, the temperature levels and the performance of a heat storage system. From the technical analyses of different storage technologies results a high potential of volume reduction using latent buffer storages instead of warm water storages within a cogeneration system. The advantage of this technology is that the heat is not only stored in a so called sensible way but also in a latent way, when changing the phase at the solidification temperature from fluid to solid and vice versa. With this a much higher volume specific heat capacity can be practically achieved in comparison to water. In general it is differentiated between micro- and macro- capsule storages which refer to the size of the capsules including the storage medium, typically surrounded by water as carrier fluid. The following representation shows the application of macro – capsule storages with different storage media.

Another advantage of latent buffer storages with macro – capsules is, that they do not differentiate to the integration of a warm water buffer storage in a cogeneration system (compare Figure 4). Usually the storage medium is capsulated in layer cakes or pellets inside the storage tank while the carrier medium -water- circulates equal to a normal water storage between unit, storage and heat circuit of the building. This leads to a simplified technical integration into the system.

In contrast to the warm water storage, where the heat is stored layer like beginning from the top of the storage the load profile of a macro – capsule storage tank is smoother (compare Figure 6 a and b). For a maximum utilisation of the heat capacity of the macro – capsule storage the phase change temperature should be at minimum 5°C higher than the required flow temperature of the heating circuit and at minimum 5°C lower than the maximum return flow temperature of the cogeneration unit to keep the performance high. Within a 70/50 – heating system this implies a needed phase change temperature of minimum 75°C in order to achieve a permanent flow temperature to the heating circuit of 70°C. With a phase change temperature of about 75°C on the other side a maximum return flow temperature of 75 + 5°C = 80°C is required to load the storage most effectively. This would imply that the examined units (compare Table 1) are not capable to deliver the ask performance. To solve the conflict researches were made which lead to the conclusion that two different phase change materials with two different temperature levels in the right proportioning can generate the synergistic effects needed to allow high flow temperatures and at the same time limited return flow temperatures for the unit. In principle the material with the high temperature level (>75°C) is located at the top of the storage to guarantee high flow temperatures to the heating circuit on the one hand and the other material (<65°C) at the bottom of the storage on the other hand is needed to synchronise the storage properties with the maximum return flow temperature of the cogeneration unit. Figure 6 shows a drawing of the system.

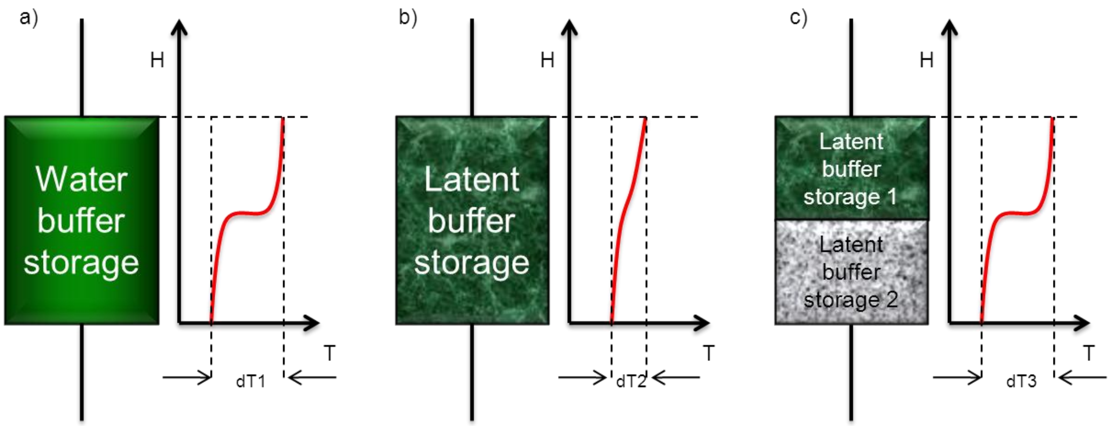

Figure 6: Example of a loading profile along the height of a water buffer storage (a), a latent buffer storage (b) and the combination of two latent buffer storages with two different solidification temperature levels (c)

To compare the practical volume reduction potential of a latent buffer storage respect to a common warm water storage tank several simulations with different flow temperatures were made. The results are shown in Figure 7.

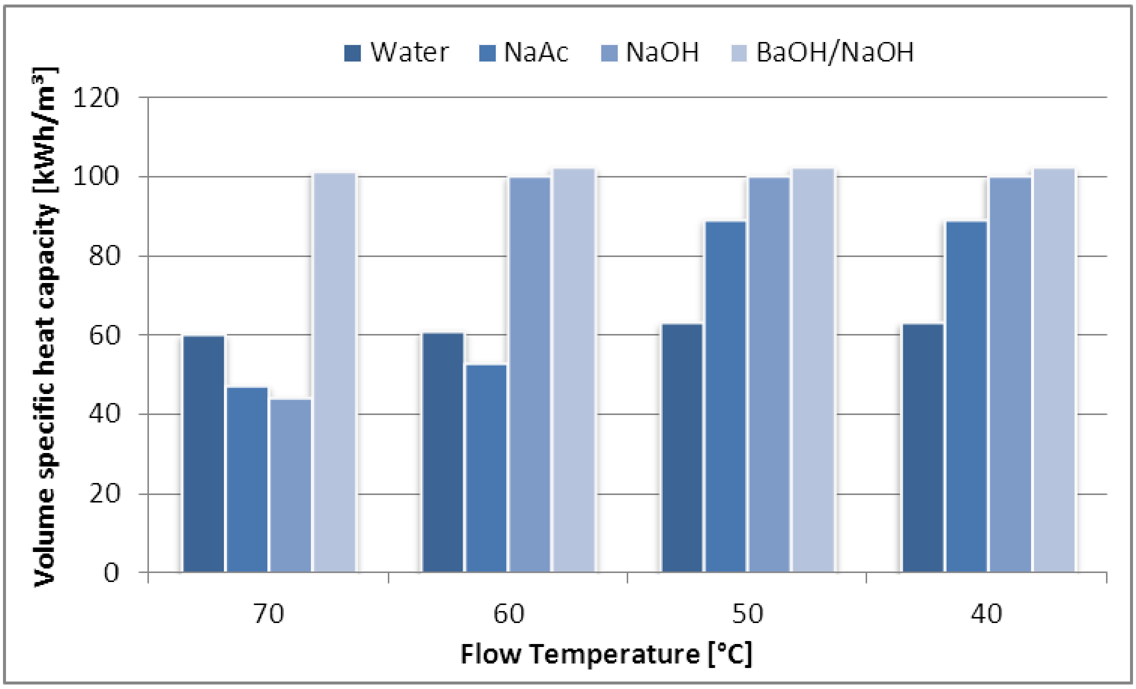

Figure 7: Practically usable volume specific heat capacity in dependence of the phase change material and the necessary flow temperature of the heating circuit compared to the prosperities of a water buffer storage [MW1]

The diagram shows the comparison of two storages with homogenous media capsules and a storage with two combined materials with a water storage. NaAc has a phase change temperature level of 58°C and NaOH a level of 65°C. The storage with a combined infill of BaOH at the top and NaOH at the bottom has two temperature levels of 78°C and 65°C. How expected it is notable that as long the phase change temperature level is higher than the needed flow temperature of the heating circuit and the flow temperature is not to high even latent buffer storages with only one phase change material and a relative low phase change level become attractive. In order to allow also a higher flow temperature of 70°C to the heating circuit which often is needed in regular households and to comply with the return flow requirements of the cogeneration unit the combination of two different materials with one high and one low temperature level become necessary. With this volume reductions from up to 40% are getting possible.

However regarding the prices of actual latent buffer storages an economic usage still is not foreseeable because of the low market penetration. The prices are up to five times higher compared to a common water buffer storage.

3.2.2. Electro chemic storage

An electro chemic storage allows an additional degree of freedom in uncoupling the heat- from the current- supply. Within a virtual power plant it can be used equal to a buffer storage to cut the peak loads at the spot market. Another possibility which will be discussed in the following is the direct current commercialisation on location. In this case the electricity is provided for the intern usage of the multi – family house with the aim to reduce the current flow from the public grid to a minimum. Because of the direct usage of the generated current the obligation of paying electricity tax, distribution grid fees and other dues drops, so that a clearly higher margin can be expected. Also in this case the boundary conditions for heat and current supply are given by the VDI guideline 4655 [VD1]. The application of the battery is orientated towards technical data sheets of several manufacturers in the market. One of the batteries with the best properties is the lithium – ion – battery which in this case is the object of contemplation.

To guarantee a high live cycle of the battery the discharge shall proceed with a favourably constant current flow. Depending on the battery voltage its electrical power is defined so the fluctuant demand in dependence on the daytime can be covered partly or during times of low demand also completely by the battery.

For live cycle reasons the maximum discharge level is limited to 80% in the simulation. The simulated control system provides a complete charging of the battery with every clock time of the cogeneration unit while the loading is preferably done during times of low spot market prices so that in every clock cycle the rest of the generated current still can be remunerated with a top price at the spot market. Figure 8 shows the interrelationship between spot market delivery and own current usage in a given simulated period of one year for different battery sizes.

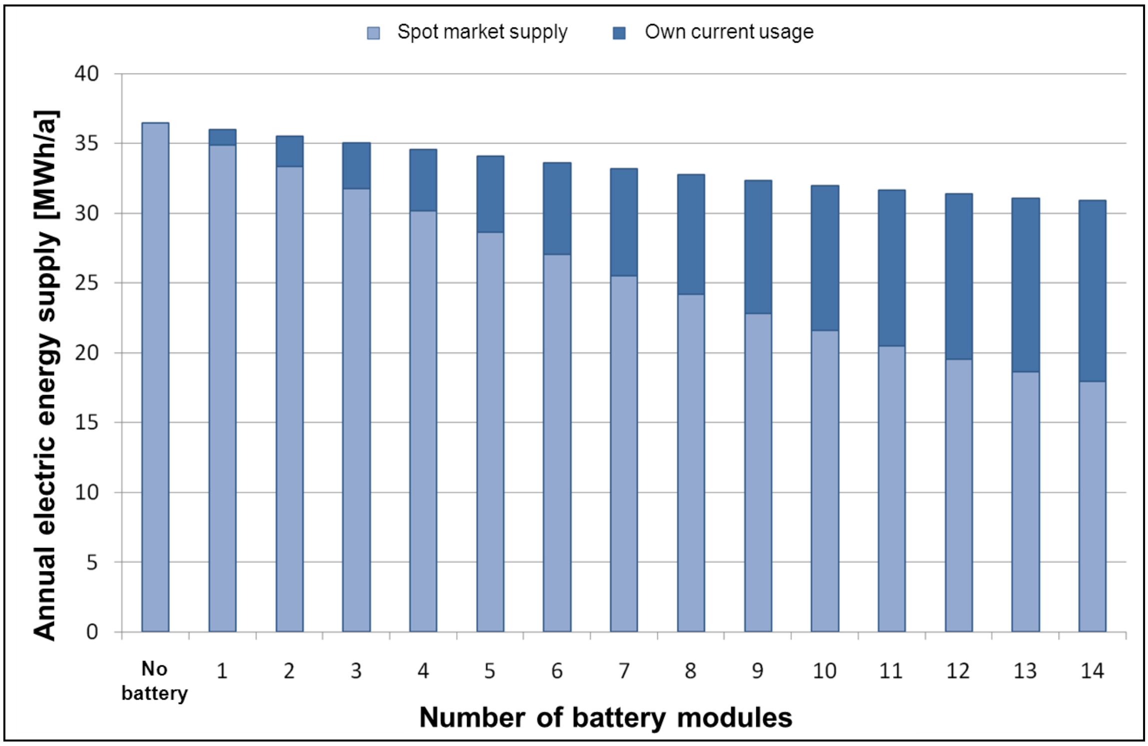

Figure 8: Annual electric supply for spot market and own current usage with different battery sizes respect to a cogeneration system without battery for the year 2008 [PI1]

It is shown that with an augmenting size of the battery the electrical business volume decreases. This is founded in the losses of the battery and its technical components. At the same time the volume traded at the spot market decreases, too, because of the necessary higher charging values. Regarding the remuneration proportions in Figure 9 it can be shown, that even if the electrical business volume has decreased the financial business volume has hardly increased. This relation results from the very high remuneration and the low fees for the own used electricity in contrast to the trade at the spot market.

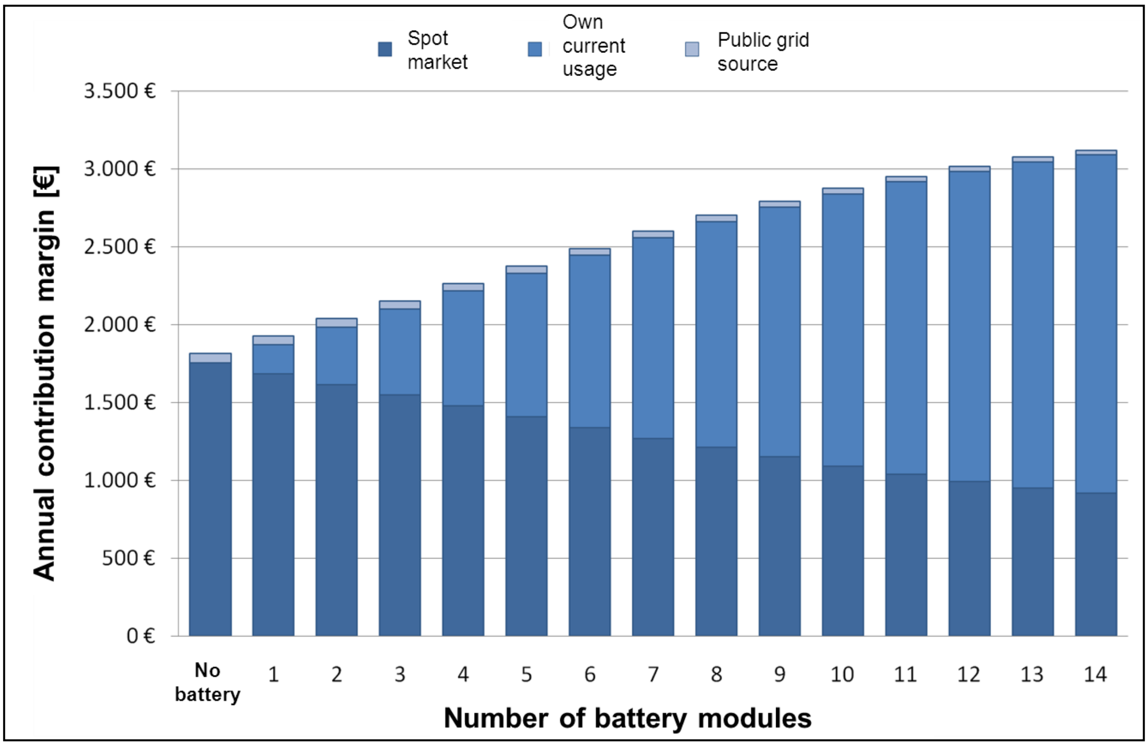

Figure 9: Annual volume of sales for spot market and own current usage with different battery sizes respect to a cogeneration system without battery for the year 2008 [PI1]

4. Conclusion

As a result of the economical reflections comes out, that the remuneration of the generated electricity at the spot market in general offers an additional benefit respect to the common base load remuneration. The participation at the market is suitable either for relatively smaller cogeneration units in combination with a peak load boiler as well as for a unit with a higher power and without peak load boiler. Here the final decision on which concept to choose is depending on the investment costs on the one hand for an additive boiler for smaller units and on the other hand higher costs for a unit with a higher power and no extra boiler. For the dimensioning of the buffer storage as a part of a cogeneration system in a virtual power plant higher requirements than for the local usage of the current are necessary. In the examined cases the volume rises from 1000l up to 2000l to enable an adequate uncoupling of heat- and current- supply. The developed simulation tool allows an optimal dimensioning of cogeneration unit and its buffer storage.

A possibility to avoid a huge footprint of the cogeneration system is the substitution of the water buffer storage with a latent buffer storage. The presented macro – capsule system is easily capable of being integrated into the system and allows a volume reduction up to 40% faced to the water buffer storage. The examinations show that the combination of two different storage media with different temperature levels can gain a clear advantage most notable in higher flow temperature needs. General disadvantage from the technical point of view is the limitation of the flow temperature so that heating systems with a necessary temperature of for example 90°C are not suppliable. No Otto – engine based cogeneration unit in this class is capable to produce the necessary high flow temperatures. Economically however the latent buffer storage yet is no option.

The integration of a battery in a cogeneration system establishes a range of new possibilities of uncoupling the heat- form the current- supply. In the given example is showed the economic benefit of using the battery to locally supply the building while charging it via the unit during times of low spot market prices. Depending on the costs of the battery components with the developed simulation tool and its results the optimal number of battery modules for a profitable integration into a cogeneration system within a virtual power plant can be determined.

5. Acknowledgements

Thanks goes to Philip Iwan and Macro Walper for the good collaboration during the researches and Christian Appel for supporting the research activities on the side of LichtBlick.

6. References

[BU1] Homepage Buderus
URL:
http://www.buderus.de/Produkte/Produktkategorien/BHKW/Loganova_BHKW_Modul-2230930.html?mid=2231644&table=techdata&mid=2231644& type
Call date June 2008

[EE1] Homepage EEX
URL:
http://www.eex.com/de/Marktdaten/Handelsdaten/Strom/Stundenkontrakte%20%7C%20Spotmarkt%20Stundenauktion/spot-hours-table/2008-01-08/PHELIX
Call date August 2008

[LB1] LichtBlick – die Zukunft der Energie
Provided information regarding the current and natural gas market
Kontact URL:
www.lichtblick.de
Call date August 2009

[MW1] Dipl. –ing. M. Walper; 10.2010; Simulation und Evaluation von Wärmespeichern in einem Verbund mit einer KWK-Anlage; Diplomarbeit

[PI1] Dipl. –ing. P. Iwan; 03.2010; Simulation und Optimierung eines KWK-Managementsystems mit Fokus auf der gekoppelten Strom- und Wärmespeicherung; Diplomarbeit

[PP1] Homppage PowerPlus Technologies GmbH
URL:
http://www.ecopower.de/Technische-Daten.28.0.html
Call date July 2008

[SE1] Homepage SenerTec
URL:
http://www.senertec.de/show_pdf.php?name=technisches_datenblatt
Call date July 2008

[VD1] VDI – guidline 4655
Referenzlastprofile von Ein- und Mehrfamilienhäusern für den Einsatz von KWK – Anlagen; Beuth Verlag GmbH, 10772 Berlin 2008

7. List of figures and tables

8. Figures and tables

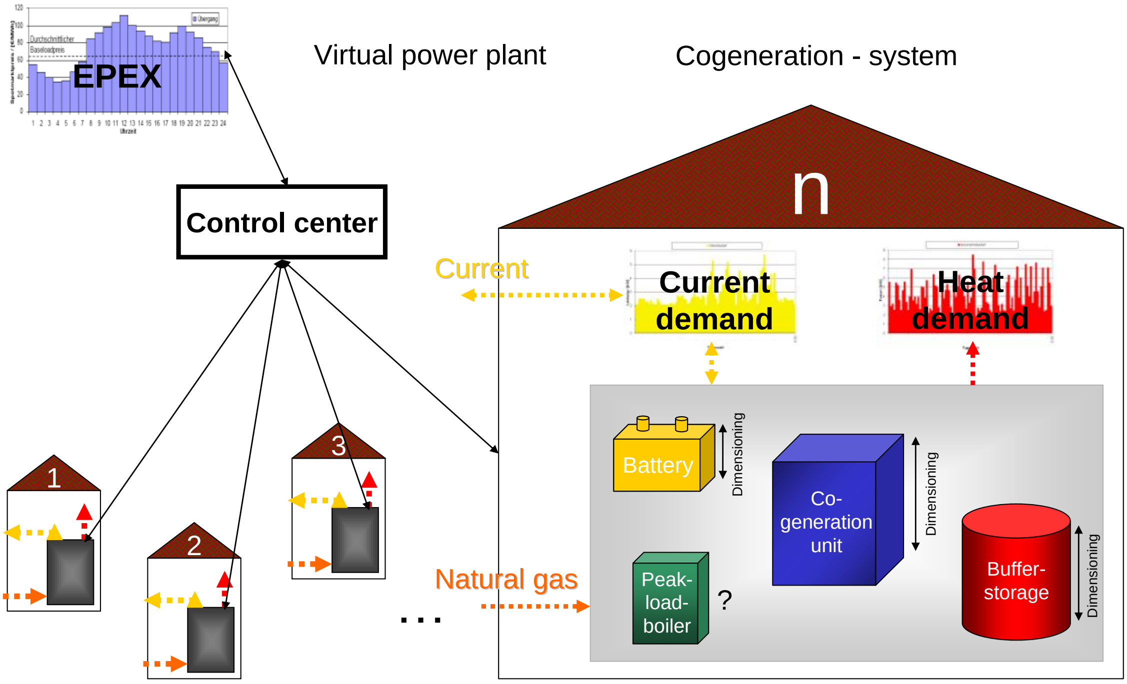

Figure 1: Overview of the interdependences of the examined components in the virtual power plant

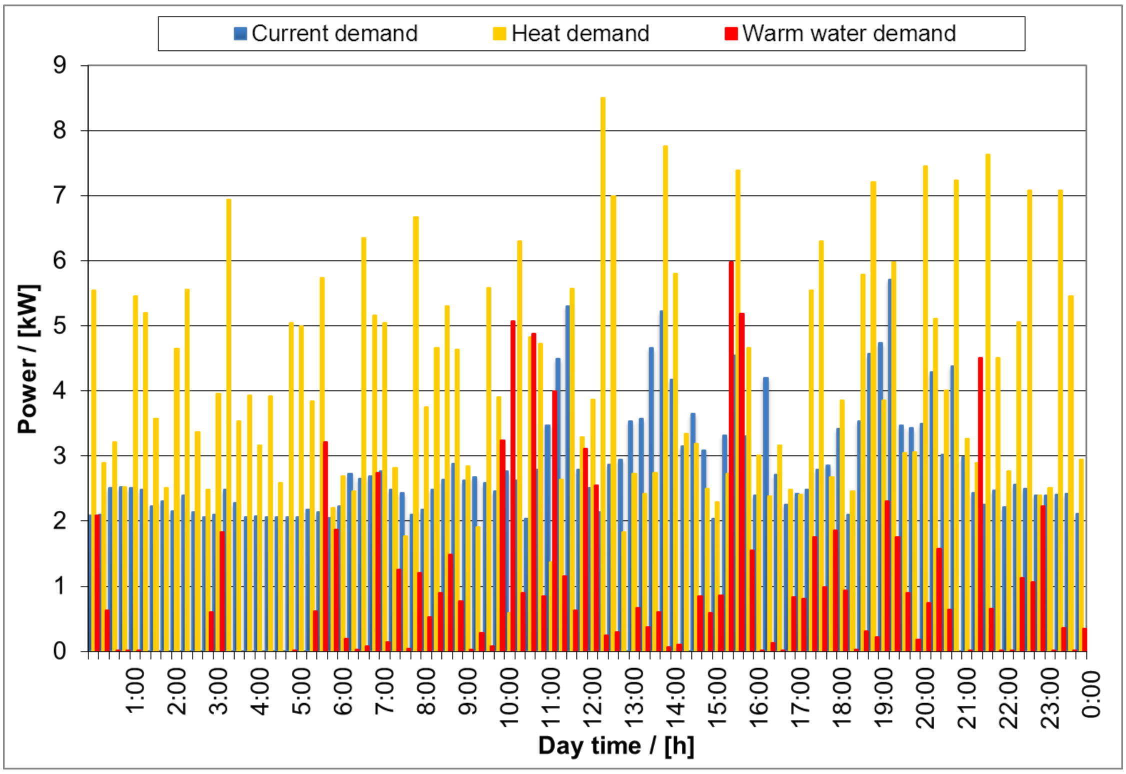

Figure 2: Example of thermal and current profiles of an 8 flat multi – family house with an annual thermal heat demand of 65000 kWh referred to the VDI guideline 4655 [VD1]

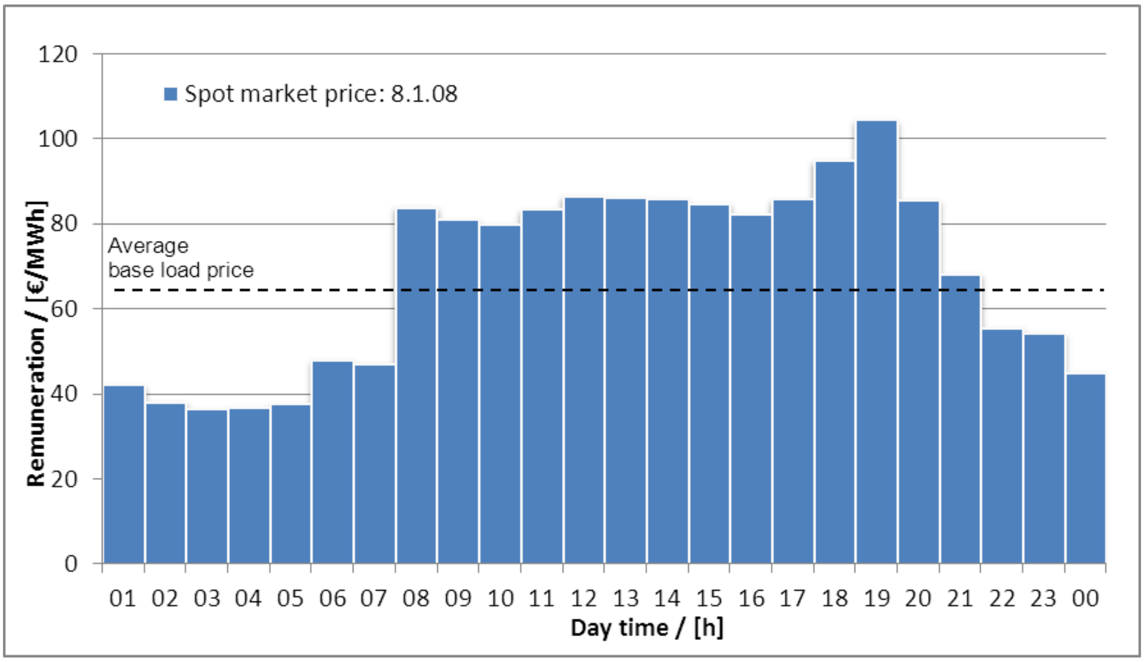

Figure 3: Development of the spot market price at the 8.1.08 over the average base load price of the first 6 month in 2008 [LB1], [EE1]

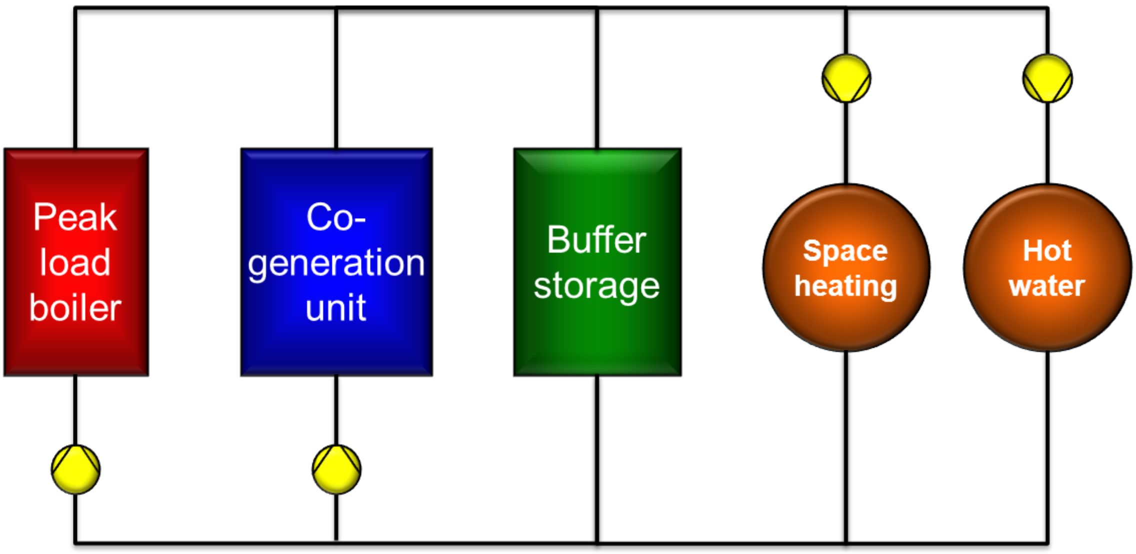

Figure 4: Overview of the technical interconnections of the single components of the examined cogeneration systems on the level of one building

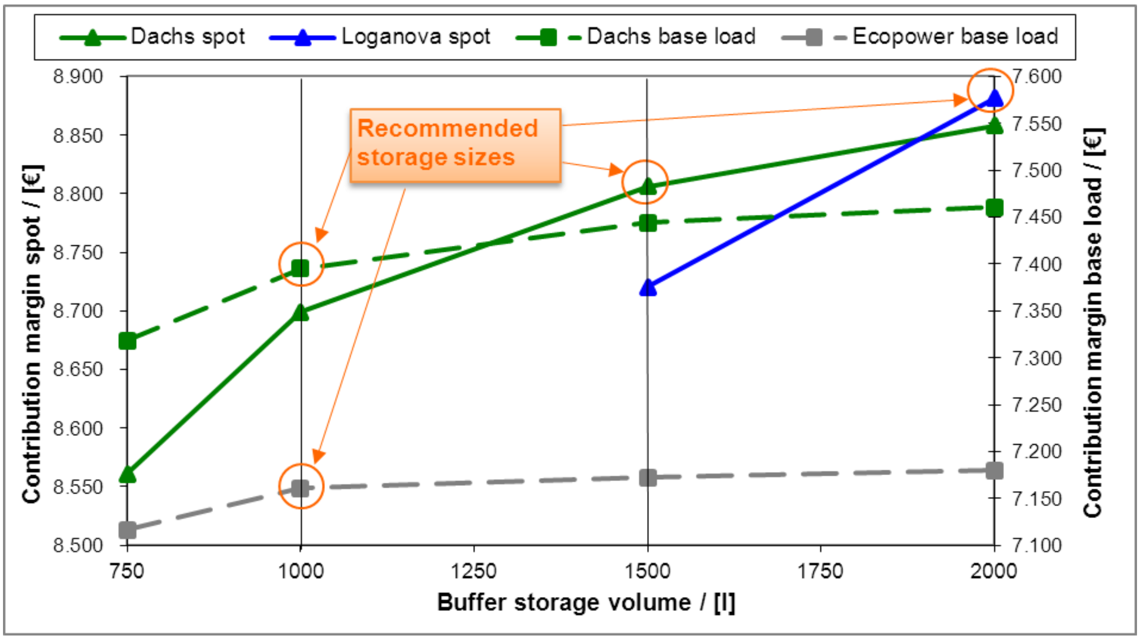

Figure 5: Quantitative influence of the buffer storage volume to the annual financial net cash flow for the remuneration at the spot market and the remuneration according to the common base load price for the year 2008

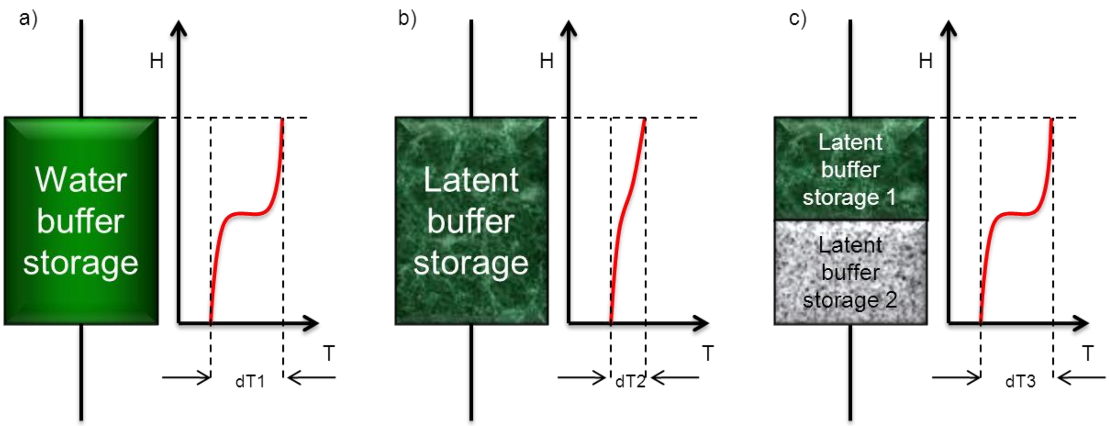

Figure 6: Example of a loading profile along the height of a water buffer storage (a), a latent buffer storage (b) and the combination of two latent buffer storages with two different solidification temperature levels (c)

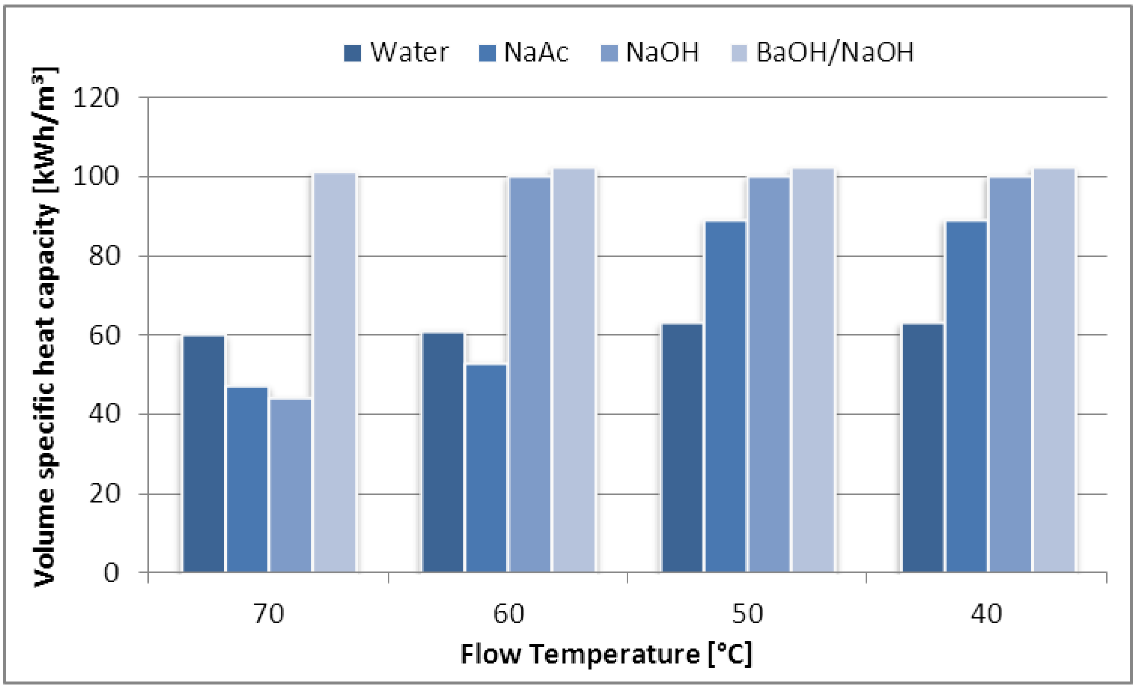

Figure 7: Practically usable volume specific heat capacity in dependence of the phase change material and the necessary flow temperature of the heating circuit compared to the prosperities of a water buffer storage [MW1]

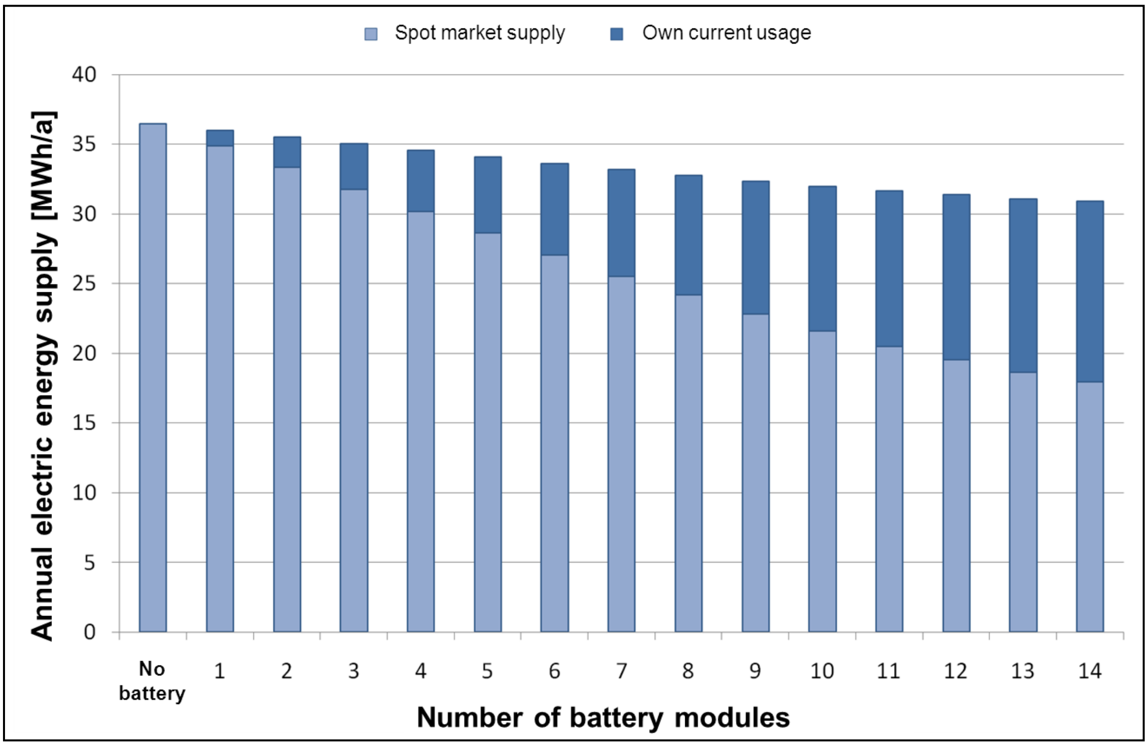

Figure 8: Annual electric supply for spot market and own current usage with different battery sizes respect to a cogeneration system without battery for the year 2008 [PI1]

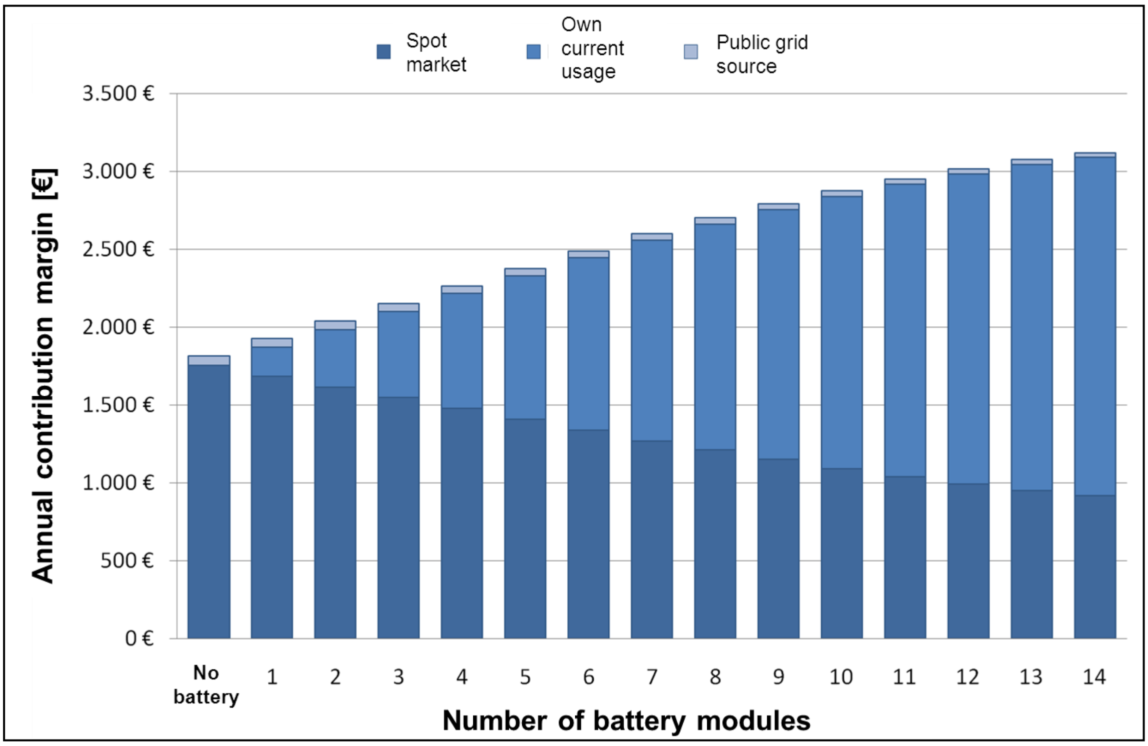

Figure 9: Annual volume of sales for spot market and own current usage with different battery sizes respect to a cogeneration system without battery for the year 2008 [PI1]

Table 1: Abstract of the data sheets for the simulated cogeneration units [SE1], [PP1], [BU1]

Manufacturer		SenerTec	Power Plus Technologies	Buderus
Type		Dachs	Ecopower (modulating)	Loganova E0204 MN-20
Fuel	-	Natural gas	Natural gas	Natural gas
Functional principle	-	Otto-engine	Otto-engine	Otto-engine
Electrical power	kW	5,5	1,3 - 4,7	18
Thermal power	kW	12,5	4 - 12,5	32
Fuel power	kW	20,5	5,9 - 19	54
Max. flow temperature	°C	83	75	85
Max. return flow temperature	°C	70	60	75
Empty weight	kg	530	395	900
Liquid capacity	kg	5	5	-
Efficiency: Electric	-	0,27	ca. 0,25	0,33
Thermic	-	0,61	ca. 0,65	0,59
Overall	-	0,88	0,9	0,92