# Strategic energy supply of a company location with focus on renewable energies

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Thesis to obtain the Master of Science Degree in

## Energy Engineering and Management

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**October 2015**

# Abstract

The objective of this thesis is the development of a sustainable concept for the strategic energy supply of a company location with focus on renewable energy sources.

For this purpose first of all the technical and economic background as well as the consequences of the development of the efficiency laws on the energy performance of buildings are highlighted. Especially the European Directive 2002/91/EC and its legal consequences for Germany are examined. Subsequently, the situation of the company site regarding these laws is analyzed and a portfolio of possibilities for improvement established and discussed. In the next step the most suitable alternatives are evaluated in a legal, technical and economical frame. Finally, the recommendation for a concept is proposed to the company and the required steps therefore exemplified.



Key words: Strategic energy supply, renewable energy sources, efficiency laws on the energy performance of buildings, European Directive 2002/91/EC



O objectivo desta tese é o desenvolvimento de um conceito sustentável para o fornecimento estratégico de energia do uma empresa com foco na energia renovável.

Com este intuito, é feito antes de mais um destaque de todas as circunstâncias técnicas e económicas assim como das consequências do desenvolvimento de leis eficazes para a performance energética de edifícios. Espificamente a directiva europeia 2002/91/EC e as suas consequências e investigada. Subsequentemente, é analisada a situação do local perante estas leis e é estabelecido e discutido um portefólio de possíveis aperfeiçoamentos. Em seguida, são avaliadas as alternativas mais adequadas num contexto legal, técnico e económico. Finalmente, é proposta uma recomendação para o conceito e os passos requeridos são então exemplificados.



Palavras-chave: Fornecimento estratégico de energia, energia renovável, leis eficazes para a performance energética de edifícios, directiva europeia 2002/91/EC

# List of Abbreviations

| | |
|---|---|
| EnEV | Energy Saving Regulation |
| RE | Renewable Energies |
| REHA | Renewable Energy Heat Act |
| PV | Photovoltaic |
| CHP | Cogeneration of heat and power |
| NPV | Net present Value |
| OS | Obligatory share (REHA) |
| CR | Coverage ratio (REHA) |
| DF | Degree of fulfillment (REHA) |
| AG | Joint stock company |
| NPB | New production building |
| HHV | Higher heating value |
| LHV | Lower heating value |
| BMS | Building management system |
| PES | Primary energy savings |
| ESM | Energy saving measures |

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# 1. Introduction

In the last years the necessity of climate protection attracted more and more notice in the world public. Especially the consequences of the anthropogenic climate change, which cannot be reversed in a short term, could be severe. The increasing emission of greenhouse gases causes a continuous temperature rise on the surface of the earth. Since the age of industrialization carbon dioxide ($CO_2$), which emerges during fossil combustion, contributes a substantial part in this issue.

This development and its possible impact are not ignored anymore in world's policy since the end of the 20th century. In the so-called "Kyoto-Protocol" from 1997 global objectives for the reduction of greenhouse gases are fixed for the first time. In this frame the European Union as entity is bound to contribute to this movement. (Marquardt, 2011 pp. 17-19) The energy and especially heat supply of buildings in Europe is widely based on fossil combustion. Therefore, in the building sector a huge potential for $CO_2$-Reduktion can be identified. (Dirk, 2010 p. 1)

Figure 1 illustrates that heating in buildings ("Raumwärme", 29 %) and domestic hot water ("Warmwasser" 6 %) form an essential part of the overall energy demand in Germany. Hence, a reduction of consumption in this sector would consequently have a huge impact on the overall $CO_2$-balance. (BMWi, 2014 p. 17)

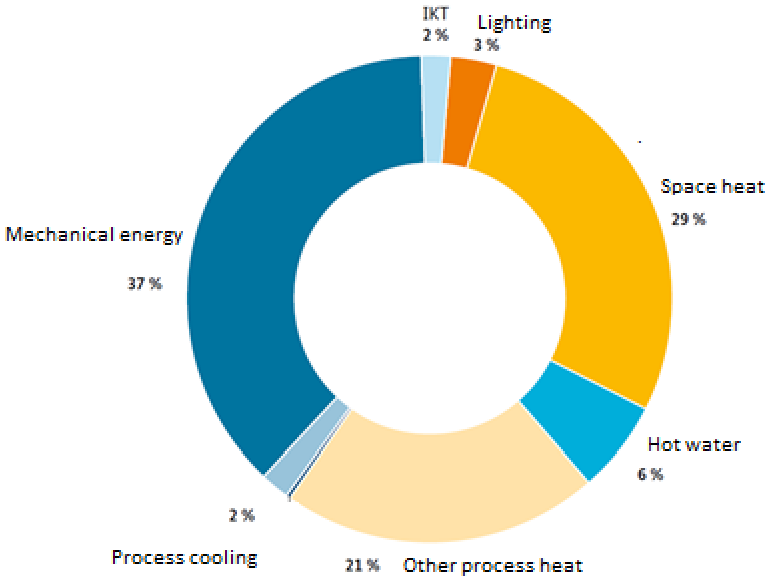


**Figure 1: Energy consumption in Germany, adapted from (BMWi, 2014 p. 17)**

Seeing that development in 2002 the European Parliament introduces the Directive 2002/91/EC on the energy performance of buildings that has to be implemented on the national levels until 2006. Henceforward, the energy consumption of buildings should be balanced not only including heat supply, but also energy demand for refrigeration and lighting. Furthermore, the directive obligates the owner of buildings to certificate the energy efficiency and forces the integration of renewable energy sources or other energy-saving measures like the cogeneration of heat and power into the energy supply of buildings. (Marquardt, 2011 p. 22)

The German government responds in 2006 with a draft and in 2007 finally with the passage of the amendment of the Energy Saving Regulation (EnEV) (Marquardt, 2011 p. 23), which is tightened again in 2009 and 2014 (BMWi). In addition, in 2009 the Renewable Energy Heat Act (REHA) that obligates new buildings to be supplied partially by renewable energy sources is passed. (Marquardt, 2011 p. 23)

## 1.1 Motivation and objective of the thesis

The company recently faces problems with the compliance of the laws on the energy performance of buildings at one of their production locations, which is the reason for offering a master thesis. Consequently, the purpose of this work is to analyze the energy laws, identify their effects on the location of the company and to develop a strategic concept that ensures a long-term compliance of those laws.

This version of the master thesis will be published. Therefore, the content is reduced by confidential parts and the name and location of the company is left out. The references that contain information about the identity of the company or collaborating companies are anonymized.

# 2. Fundamental knowledge – technology and economics

This chapter contains some technical knowledge which contributes to the understanding of the thesis. Furthermore, some economical basics concerning an investment appraisal are introduced.

## 2.1 Heat supply

The heat supply of buildings ensures a certain level of room temperature and the availability of hot water in buildings. This task can be executed by different technical components.

### 2.1.1 Combined heat and power unit (CHP)

A combined heat and power unit is a cogeneration unit that produces mechanical and thermal energy by combustion of a fuel. (Fehrenbach, 2013 p. 6)

Mechanical energy is produced in a combustion unit (motor or turbine) and under the use of a generator in electrical energy converted. The waste heat from the process (and that is the difference between conventional electricity production and cogeneration) is collected and transferred to a heat cycle where the heat energy is distributed to its consumers. This leads to a very high efficiency of the overall process and efficiency factors of over 90 % can be reached by this technology. (Marco Bäckeralf, 2005 p. 40)

There are different types of cogeneration units, one of them is a combined heat and power unit with gas motor. A mix of air and gas is admitted, compressed and burned under the production of mechanical energy (rotation) in the motor. The energy is transferred via a shaft to the generator where it is converted into electrical power by electromagnetic induction in the generator. The waste heat of the process is contained in the exhaust gases and cooling water and can be extracted by heat exchangers into another heat cycle (for example used for heating supply of buildings). (Dietram Castorp, 1999 p. 269) Figure 2 illustrates the schematic composition of a combined heat and power unit.

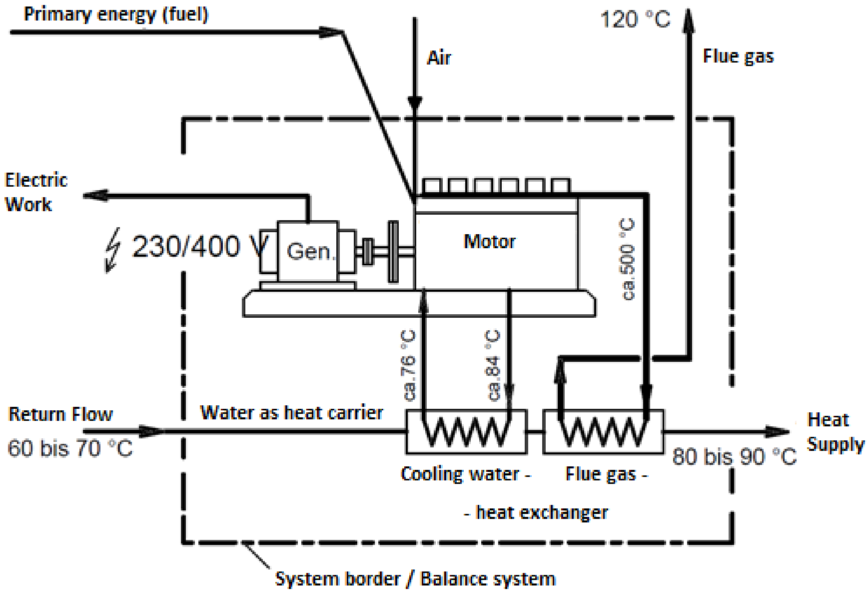


**Figure 2: Schematic composition of a CHP unit with motor, adapted from (Dietram Castorp, 1999)**

### 2.1.2 Heat exchanger

The common used medium for heat exchange is water because it is relatively cheap (in the economic perspective), not hazardous in case of leakage and has an adequate heat capacity (IGS - TU Braunschweig p. 9)

Every heat supply system consists of several heat cycles. Between these cycles the heat is transferred under the use of heat exchangers. Systems always strive for equilibrium, therefore temperature differences are always balanced via heat transfer (Dietram Castorp, 1999 p. 122). This effect is used in a heat exchanger.

In an indirect heat exchanger two fluxes with different temperatures are entering the isolated functional unit and the temperatures adapt (conduction) without contact of the media. The colder flux is warmed up and the warmer flux converged down. Both fluxes can consist of water (e.g. primary and secondary heat cycle of the heating supply for buildings) or different media (exhaust gas and water in the heat exchanger of a combined heat and power unit). (Technical institute for education - Christiani p. 216)

In direct heat exchangers several fluxes of media are mixed in the functional unit. This type of heat exchanger is not relevant for the further understanding of the thesis.

In Figure 3 a so-called “shell and tube heat exchanger“ (subgroup “straight-tube heat exchanger”), an example of the indirect mode of operation, is depicted. The cold fluid enters the isolated unit and is heated up by the warm fluid that is passing the volume in tubes. (Technical institute for education - Christiani p. 217)

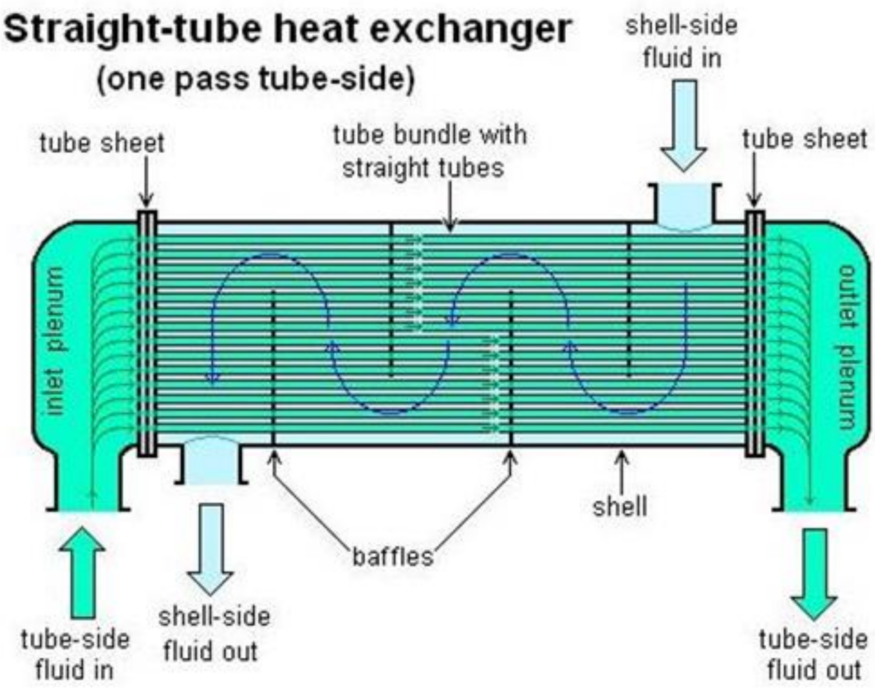


**Figure 3: Shell and tube heat exchanger (Bright Hub Engineering)**

## 2.2 Solar radiation

Solar radiation is generated in the nuclear fusion processes in the sun. The main step of this process is the fusion of hydrogen nuclei to helium nuclei. In this reaction a lot of energy is set free which is emitted by the sun as radiation. (Drück, 2012 p. 7)

There are two ways in technology to use this energy.

### 2.2.1 Photovoltaic (PV)

The generation of electricity with photovoltaics is very widespread in Germany already. Using the so called "photo-electric-effect" it is possible to convert solar radiation directly into electric energy without any $CO_2$ - emission. Due to those facts this is a pretty sustainable use of the solar energy and therefore it receives political support in the German energy sector. (Mertens, 2013 p. 18)

The essential part of a photovoltaic installation is the solar cell which usually consists of the material silicon. The latter is impurity doped (foreign atoms) and therefore in the semiconductor cell a material transfer, which can produce an electric field in the cell, can take place. By the energy contained in the solar radiation load carriers can be released out of the crystals and be transported to the outside by the electric field. A direct-current voltage in the range of 0,5 Volt emerges and can be used. A series connection of a lot of these cells adds up to a solar module (Figure 4) which also includes further components like mechanical devices and the protection. (Mertens, 2013 p. 30)

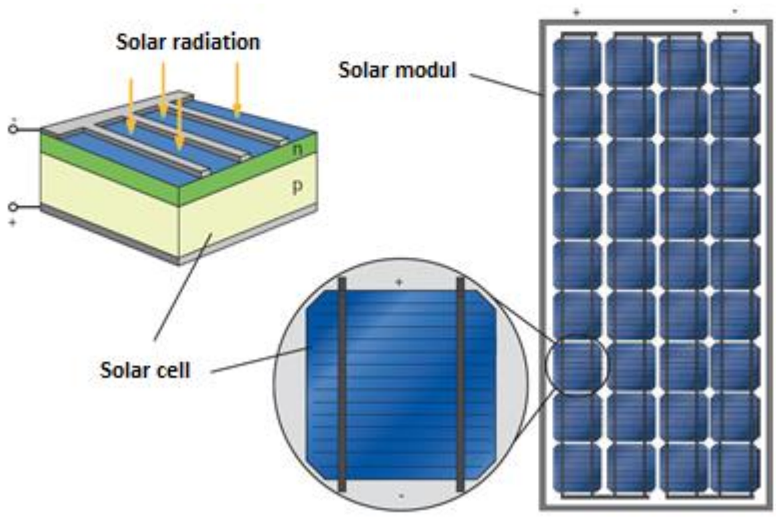


**Figure 4: Solar cell and solar module, adapted from (Mertens, 2013 p. 30)**

An installation of PV consists of several solar modules that are connected in series (or parallel) and deliver direct current. Therefore, an inverter is used to convert the direct into alternating current. The latter can finally be fed into the public electricity grid. (Mertens, 2013 p. 30)

### 2.2.2 Solar thermal energy

Another way of utilization of the solar energy is the solar thermal way, where energy of the sun is directly used in form of heat. In a passive way this is already done in almost all buildings by the absorption of heat on the surfaces and the transport (conduction) of the energy to the interior. Active solar systems are able to collect the solar radiation with the help of absorbers and convert it into heat energy that can be transported to consumers by the use of a medium as heat carrier. (FIZ Karlsruhe GmbH, 2008 p. 2)

For small-scale applications (e.g. hot water in domestic buildings) flat plate collectors (Figure 5) are widely spread. They have an isolated case with a transparent cap (normally glass) covering the absorber to reduce conductive and convective heat losses. (FIZ Karlsruhe GmbH, 2008 p. 3)

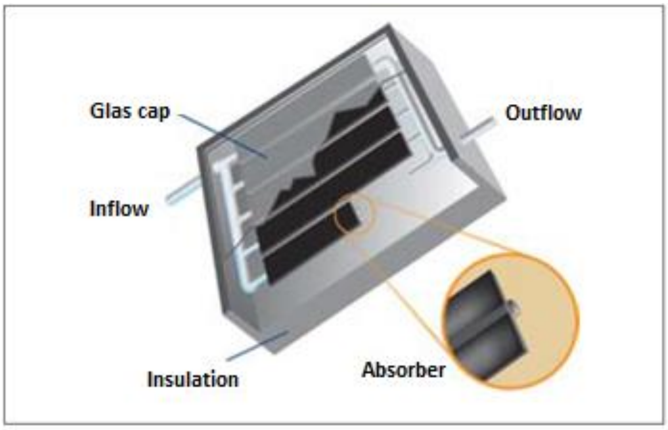


**Figure 5: Flat plate collector, adapted from (FIZ Karlsruhe GmbH, 2008 p. 3)**

In case of solar thermal applications with higher performance the radiation is concentrated by reflection under the use of mirrors and in that way high temperatures are produced. An example for that is parabolic trough power plant that is illustrated in Figure 6.

**Figure 6: Parabolic trough power plant (DLR, 2005)**

The produced heat can be used for heat supply or to generate $CO_2$-free electricity (a medium is heated and expanded in turbines). (FIZ Karlsruhe GmbH, 2008 p. 5)

## 2.3 Biomass

Plants can convert the energy of the solar radiation via photosynthesis in organic material with a high energy-density. The term biomass therefor embraces all carbonaceous substances with organic origin.

(Martin Kaltschmitt, 2009 pp. 1-2) A big advantage of this kind of renewable energy compared to others (e.g. wind or solar) is the spatial decoupling of production and utilization.

In the frame of the Renewable Energies Heating Act (see 3.3 “Erneuerbare-Energien-Wärmegesetz” – Renewable Energies Heating Act) biomass is categorized by its state of matter (solid, liquid, gaseous) regarding the state as secondary energy (the interstage before the conversion in used energy). (Martin Kaltschmitt, 2009 p. 5)

The thermo-chemical conversion in form of gasification of solid biofuel into synthetic gas is very common. The synthetic gas can be transformed into a gas mix with a high proportion of methan by further steps. Subsequently, this gas mix can be used as fuel in stationary applications like the cogeneration of heat and power in a CHP (see 2.1.1 Combined heat and power unit (CHP)). (Martin Kaltschmitt, 2009 p. 5) Figure 7 illustrates this type of application and therefore shows a biomass plant.

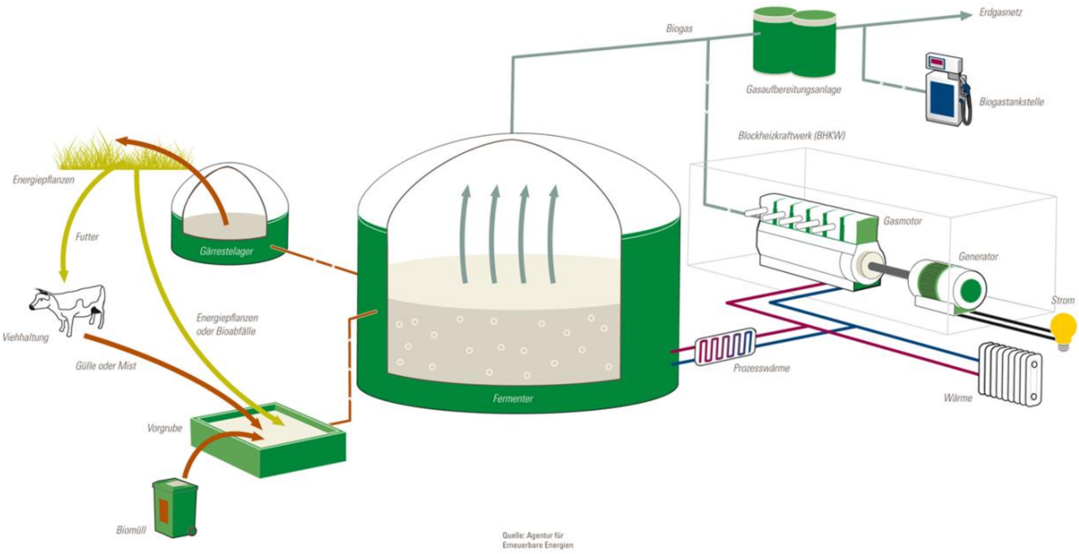


**Figure 7: Schematic composition of a biogas plant (Agency for renewable energies)**

## 2.4 Geothermal energy

The term geothermal energy refers to the energy that is stored as heat below the solid surface of the earth. It essentially consists of the residual heat of the formation of the earth (Conversion of kinetic energy via adsorption of matter (Institue for buiding and solar technologies - TU Clausthal, 2015)) and of heat that is continuously produced during the radioactive decay of isotopes (e.g. Uranium 235/238) in the core of the earth.

This energy can be used for heat supply or for the production of electricity. An example is the hydrothermal application in which heat energy is extracted from thermal water in very deep areas. First of all a well has to be drilled to extract the hot water that later flows through a heat exchanger and back to the ground. (Institue for buiding and solar technologies - TU Clausthal, 2015) Figure 8 shows this type of application.

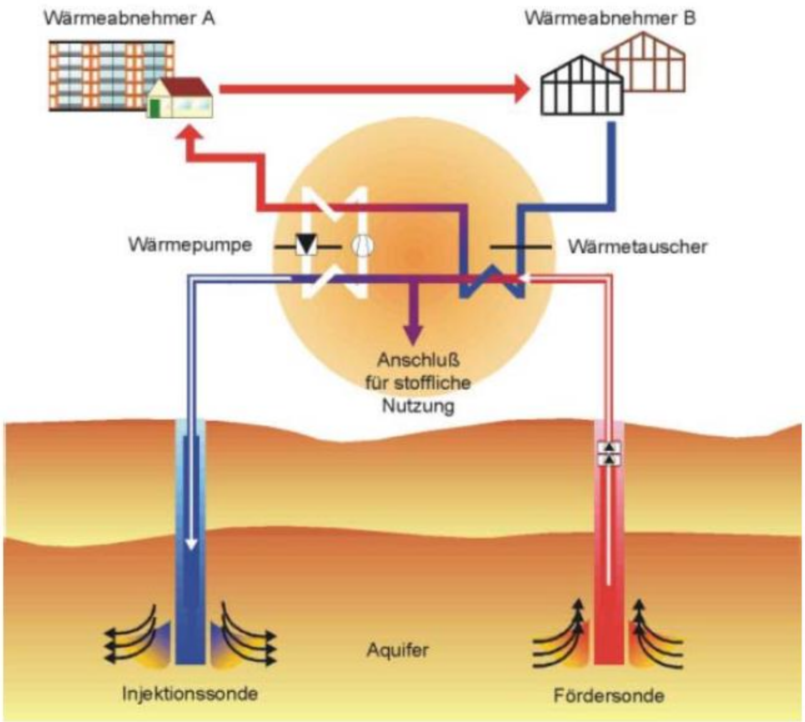


**Figure 8: Hydrothermal geo-energy (Institue for buiding and solar technologies - TU Clausthal, 2015)**

## 2.5 Methods and models

This subsection gives a short overview over the methods and models used in this thesis.

### 2.5.1 Energy systems modelling by block diagrams

An energy analysis by modelling is useful to determine the energy required for the production of a product and to save energy by adapting the process. For that purpose all energy flows which enter the system as well as the outflow (in form of the produced good) have to be identified and clear system boundaries have to be defined.

Figure 9 illustrates a block diagram of an energy system analysis. For the production of a good ($m_3$) by operation A, material inputs (or other input) as well as energy input is required. The residues represents left overs, losses or waste. The specific energy consumption of the operation is determined by the ratio of the energy consumption of operation A (influx energy) and the produced units of the operation (see equation (1)) (Ferrão, 2015).

$$\boldsymbol{Specifc\ energy\ consumption} = \frac{\boldsymbol{Energy\ consumption\ \ of\ operation\ A}}{\boldsymbol{Production\ of\ operation\ A}} \qquad \textbf{(1)}$$

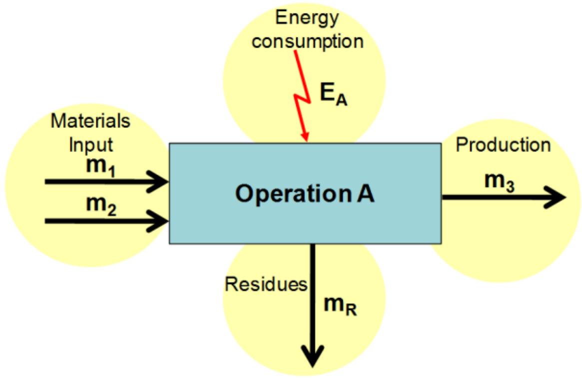


**Figure 9: Energy system model - block diagram (Ferrão, 2015)**

### 2.5.2 SWOT-Analysis

A swat analysis is a structured method to develop strategies based on the evaluation of the strengths (S), weaknesses (W), opportunities (O) and threats (T) involved in the underlying issue. An external analysis provides realistic opportunities with high potential and also identifies possible threats coming from the environment. The internal analysis is related to strengths and weaknesses of the company (can also be a decision, issue, person, etc.). By forming a matrix based on the results of both analyses (see Table 1), different strategies can be developed. (Pelz, 2015)

**Table 1: SWOT-Matrix (Pelz, 2015)**

| SWOT-Matrix | | External Analysis | |
|---|---|---|---|
| | | **Opportunities** | **Threats** |
| **Internal analysis** | **Strengths** | **SO-Strategies** | **ST-Strategies** |
| | **Weaknesses** | **WO-Strategies** | **WT-Strategies** |

Identifying SO-Strategies is the optimal case, because strengths of the company in combination with opportunities from the environment lead to a high potential. WO-strategies are ways to eliminate internal weaknesses to benefit from external possibilities, which means to transfer weaknesses to strengths. In ST-Strategies internal strengths are used to confront external risks. The most problematic area is the confrontation of internal weaknesses with external threats. WT-Strategies have to be developed to reduce internal weaknesses and to minimize the effects of external threats on the company. The necessity of too many of those strategies suggests a critical situation of the company. (Pelz, 2015)

## 2.6 Investment appraisal

This section introduces the basics of a dynamic (due to discounting values with interest rates) investment appraisal.

### 2.6.1 Net present value (NPV)

The net present value enables the comparison of investments transacted at any time and with different lifetimes.

The NPV of an investment results from present cash-flows and the discounting of future cash-flows $z_t$ (at time t) under the use of an interest rate i which is usually determined by the investor.

$$NPV = z_0 + \frac{z_1}{(1+i)^1} + \cdots + \frac{z_n}{(1+i)^n} = \sum_{t=0}^{n} \frac{z_t}{(1+i)^t} \quad \textbf{(2)}$$

All the expenditures are balanced negatively and the money received positively. That is the reason why the investment with the highest NPV is considered as the most profitable one. (Günther, et al., 2014 pp. 26-29)

The so-called payback period describes the period of time, after which the initial investment is compensated by the cumulated positive cash-flows in the future (see Figure 10).

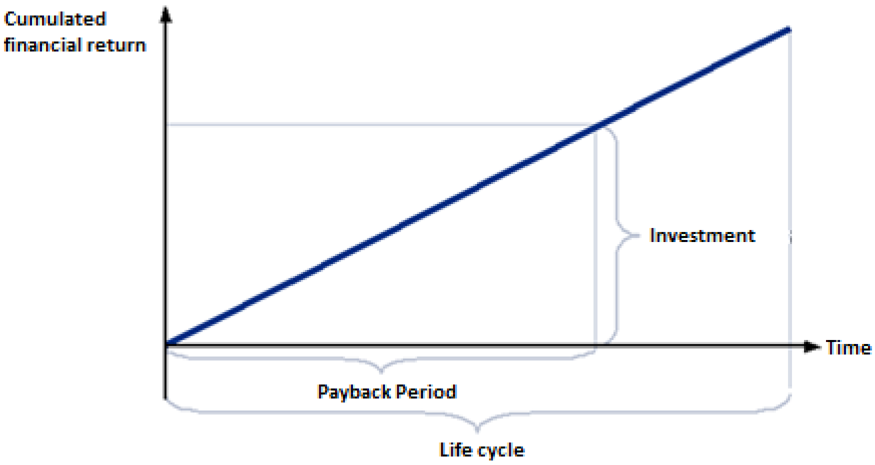


**Figure 10: Payback period, adapted from (Warnecke, 1996 S. 55)**

The payback period can be computed under the use of equation (3). (Günther, et al., 2014 p. 43)

$$\min \{n | NPV(n) = -z_0 + \sum_{t=0}^{n} \frac{z_t}{(1+i)^t} \geq 0\} \quad (3)$$

For linear payments of interest (no compound interest) the nominal annual interest rate $i_{nom,an}$ is used. If the payments occur in a higher frequency f than a year, the relative interest rate $i_{rel,f}$ can be proportionally determined with equation (4). (Rudl, 2013 p. 17)

$$i_{rel,f} = \frac{i_{nom,an}}{f} \quad (4)$$

### 2.6.2 Annuity

The use of the economical construct annuity allows distributing the NPV of an investment into periodic and continuous payments of the same amount of money. The discounting of these payments produces the NPV. The periodic payments have a lifetime n and are discounted with the interest rate i. (Günther, et al., 2014 p. 41) Equation (5) illustrates the method of annuity.

$$NPV = \frac{A}{(1+i)^1} + \frac{A}{(1+i)^2} + \cdots + \frac{A}{(1+i)^n} = A \cdot \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n}\right] \quad (5)$$

# 3. Legislative base for the energy performance of buildings

In this chapter the development of the European and German legislation concerning the energy performance of buildings is depicted. For that the process from the agreement in the Kyoto-protocol (reduction of $CO_2$-emissions) to the European (Directive 2002/91/EC and Directive 2010/31/EC) and German national law (Energy Saving Regulation (EnEV) and Renewable Energies Heating Act (REHA)) is focused. (Marquardt, 2011 p. 22) The parts of the laws that are relevant for companies are summarized and set in context. All the basic ideas and principles are explained, exact numbers are disclaimed in this chapter.

## 3.1 Directive 2002/91/EC

The Directive 2002/91/EC concerning the energy performance of buildings obligates the European countries to pass several laws for buildings. This is the base of the legislative development of the past years in that sector. However, the citizens are only bound to comply with those laws after the national implementation. (Hans-Dieter Hegner, 2010 p. 15) The main content of the directive are summarized in the following part of the thesis.

### 3.1.1 Common methodology for calculating the energy performance of buildings

All member states of the European Union have to introduce a common methodology for calculating the energy performance of buildings on a national or regional level. Besides the heating system and the hot water supply also the refrigeration, the ventilation system and the lighting have to be balanced. Furthermore, the calculation should also consider the integration of renewable energies (RE) and other measures to improve the energy efficiency (e.g. cogeneration). (European Parliament, 2002)

### 3.1.2 Minimum standards on the energy performance of new buildings

Having a lot of cultural and climatic diversity, the European Union is a geographic area too big to cover with the same laws. That is the reason why for the energy performance no general minimum standards are set by the European parliament. (Hans-Dieter Hegner, 2010 p. 17) The laws should rather be designed on national basis considering technical, economic and functional backgrounds. The use of alternative systems like renewable energies or other measures (e.g. cogeneration) has to be considered already in the state of planning and designing a building. (European Parliament, 2002)

### 3.1.3 Minimum standards on the energy performance of existing buildings

A building with a useful area over 1000 m² has to be adapted to the minimum standards of the law if it is renovated. If only some areas are renovated those have to comply the requirements. (European Parliament, 2002)

#### 3.1.4 Inspection of boilers and central air-conditioning systems

Central-heating boilers with nominal power higher than 100 kW have to pass an inspection every two years. Heating systems with a nominal power over 20 kW and that are older than 15 years, have to be entirely inspected once to weigh up the necessity of replacement. Also systems for air conditioning with a nominal power higher than 12 kW have to undergo regular inspections including a determination of the efficiency. (European Parliament, 2002)

#### 3.1.5 Energy certificates

If an owner of a building wants to sell or rent a building, an energy certificate regarding the energy performance of the building has to be existent. The certification lasts 10 years and has to contain valid legal norms and comparative characteristic numbers. (European Parliament, 2002)

#### 3.1.6 Directive 2010/31/EC

The Directive on the energy performance of buildings is recasted in 2010 with the Directive 2010/31/EC. It expands the regulations of the Directive 2002/91/EC by the following aspects (relevant for the issue of this thesis) (Parliament, 2010):

- Introduction of nearly-zero energy buildings until 2021 by the integration of renewable energies coming from the building's environment
- All buildings have to integrate renewables (independent of the area)
- Cost-optimal calculation methodology for energy requirements of buildings
- Installation of a control system for energy certificates

## 3.2 "Energieeinsparverordnung" – Energy Saving Regulation

With the introduction of the Energy Saving Regulation (EnEV) in 2002 Germany forces improvements in the energy performance of buildings parallel to the European movement. The law passes the courts in the same year like the Directive 2002/91//EC and already covers a lot of its guidelines. (Hans-Dieter Hegner, 2010 pp. 16-17) By the introduction the German government pursues the objective to have a climate-neutral building stock in Germany in 2050. (German Government, 2013 p. 7) Launching the amendment of the Energy Saving Regulation in 2007 (EnEV 2007), the EU-directive is entirely transferred to national law. In 2009 the guidelines are tightened again (EnEV 2009). (Marquardt, 2011 p. 23) In 2010 the European parliament releases an amendment of the Directive (Directive 2010/31/EC) which should also be converted to national law in the following years. As a consequence, the German government reacts by passing the Energy Saving Regulation 2014 (EnEV 2014) that is still in force until today. (German Government, 2013)

The EnEV 2014 includes all requirements of the European Directive, nevertheless in this section only the aspects that are relevant for companies are mentioned. All the legislative content is extracted from attachment 2 "Requirements for non-residential buildings" of the regulation. (German Government, 2013 pp. 37-49)

### 3.2.1 Limits for the annual primary energy requirement

The annual primary energy requirement of a non-residential building that is built or renovated (more than 50 m² new useful area in combination with a new heating system) is not allowed to exceed the value of a reference building with the same geometry, ground area, orientation and utilization. (German Government, 2013 p. 37) To check the fulfillment the energy requirement for heating, cooling, hot water, ventilation and lighting as well as the influence of solar radiation and heat losses are made up in the balance. The energy demand of the production machinery in the building is not considered. The reference value is declared in energy requirement per area and year. (German Government, 2013 pp. 37-49)

With the so-called primary energy factor also processes in advance are considered in the determination of the primary energy requirement. The factor describes the ratio (see equation (6)) between primary energy requirement (includes the energy that is needed in advance, for example while extraction, processing and transport (Dirk, 2010 p. 384)) and delivered energy demand (energy available to the supply system to feed the costumers with useable energy (Dirk, 2010 p. 384)). By law (and not real estimation) renewable energy possesses a primary energy factor of “zero”. (German Institute for Standardisation, 2011 p. 67)

$$f_p = \frac{primary\ energy\ requirement}{delivered\ energy\ requirement} \tag{6}$$

### 3.2.2 Limits for the heat transfer coefficients

Heat losses through the surface of a new or renovated (more than 10 % of the building’s surface renewed (German Government, 2013 p. 11)) building (or building envelope) can be limited by the heat transfer coefficient. The Energy Saving Regulation 2014 contains maximum values for this coefficient for all building components. The mean value for the whole building envelope has to lie below that limit. (German Government, 2013 p. 43) The heat transfer coefficient possesses the unit W/m²K and describes the heat output per area per Temperature difference. (Hauser, 2003 p. 12) A smaller value consequently means less heat losses. The reference value for opaque (not transparent) buildings components for non-residential buildings is 0,28 W/m²K (EnEV 2014 with tightening 2016). The limit for transparent components is 1.5 W/m²K (EnEV 2014 with tightening 2016) and is met by standard dribble glazing.  (German Government, 2013 p. 37)

This one-dimensional requirement is only a structural measure and should be considered by the architects and the construction company.

### 3.2.3 Summer heat protection

According to the EnEV 2014, non-residential buildings are obligated to fulfill all criteria regarding the summer heat protection. There are for example characteristic values for the solar transmittance value existent. The verification has to be executed based on the DIN 4108. (German Government, 2013 p. 36)

### 3.2.4 Tightening 2016

The EnEV 2014 contains a tightening for new constructed buildings after the 1st of January in 2016. The permitted annual primary energy requirement is reduced by 25 % and the maximum of the heat transfer coefficient is downsized by about 20 % compared to the values of the EnEV 2014. (German Government, 2013 pp. 37-43)

### 3.2.5 Application of the Energy Saving Regulation

The calculation of the reference value for the annual primary energy requirement is executed using the DIN V 18599 that is introduced in section 3.4 DIN V 18599. The maximum values for the heat transfer coefficient can be extracted from a table in attachment 2 of the EnEV 2014.

Figure 11 summarizes the content of the regulation regarding companies. If the requirements cannot be met, the construction permit is refused.

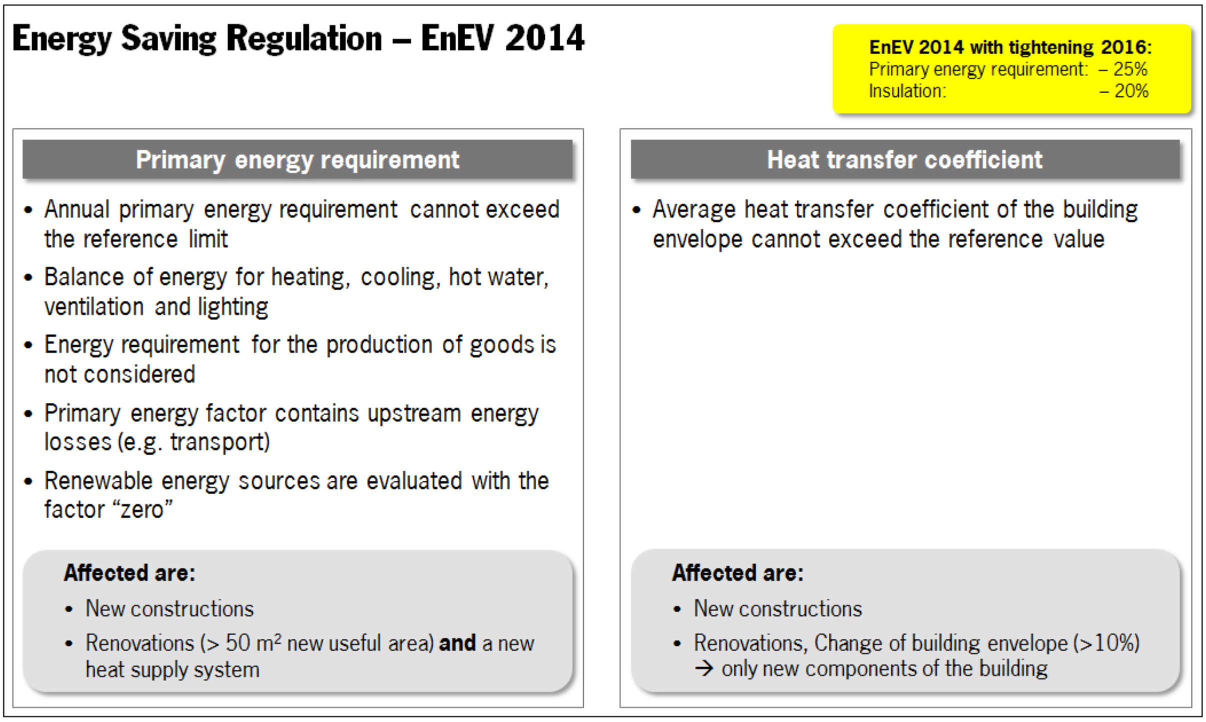


**Figure 11: Summary of the EnEV for non-residential buildings, own design**

## 3.3 "Erneuerbare-Energien-Wärmegesetz" – Renewable Energies Heating Act

As a consequence of the guideline concerning the integration of renewable energies in the Directive 2002/91/EC (see section 3.1 Directive 2002/91/EC) the Renewable Energies Heating Act (REHA) is introduced in Germany. In the special interest of climate protection and conservation of fossil resources the act forces measures to a higher level of sustainability in the heating sector. The German government aims to have a share of 14 % of heat supply by renewable energies in 2020. (German Government, 2008 p. 1) In this section of the thesis all aspects of the REHA that are relevant for companies are described.

All new constructed buildings, including non-residential ones, with a useable area of more than 50 m² are obligated to have a proportionate use of renewable energies in their heating and cooling system. Alternative replacement measures must be implemented. Whereas the EnEV relates to the primary energy requirement, the REHA refers to useable energy (heating and cooling) which the end consumer has actually available. The renewable (or replacement measures) have to cover certain shares of that kind of energy. (German Government, 2008 pp. 4-5)

### 3.3.1 Integration of renewable energies

Table 2 summarizes all potential renewable energy sources that can contribute to the fulfillment of the Renewable Energy Heating Act. Furthermore, to every technology an obligatory share is assigned. The obligatory share (OS) regulates which percentage of the heat and cooling supply has to be covered by the particular renewable energy source (supposing this is the only technology that contributes) to fulfill the law. This means, relating to Table 2, that in case of (for example) solar radiation as the only source of renewable energy, the proportion of heat supply by this RE source has to be 15 % of the overall heat. In case of, for example, gaseous biomass, the bio-heat needs to cover 30 % of the overall heat to fulfill the law. Furthermore, all technologies can be combined, so if two technologies would both meet half of their required obligatory share, the law would also be complied.

**Table 2: Obligatory share of the RE in the REHA (German Government, 2008 pp. 5-6)**

| Technology | Obligatory share in % |
|---|---|
| Solar radiation | 15 |
| Gaseous biomass | 30 |
| Liquid biomass | 50 |
| Solid biomass | 50 |
| Geothermal energy | 50 |
| Cooling from RE | 50 |

The integration of solar radiation refers only to the usage of solar thermal installations (2.2.2 Solar thermal energy) because photovoltaics (2.2.1 Photovoltaic (PV)) do not directly contribute to the heat or cooling supply. (German Government, 2008 p. 13)

Gaseous biomass only contributes to the REHA if it is burned in a cogeneration unit or a modern boiler with high efficiency. The latter is also valid for liquid biomass. For solid biomass some guidelines regarding the efficiency of the burning unit have to be met (efficiency ≥ 88 % for a nominal power higher than 50 kW). (German Government, 2008 pp. 14-15)

Cooling from RE refers for example to the use of the cooling capacity of water in the environment (e.g. a lake, a river).

### 3.3.2 Replacement measures

The REHA can also be considered as fulfilled, if replacement measures instead of RE are taken. These measures are listed in Table 3 including the respective obligatory shares.

**Table 3: Obligatory share of the replacement measure in the REHA (German Government, 2008 p. 6)**

| Technology | Obligatory share in % |
|---|---|
| Plants for the use of waste heat | 50 |
| Cogeneration units | 50 |
| Energy saving measures | 15 |
| District heating or cooling | Depends on technology |

Plants for the use of waste heat are for example air conditioning installations with heat recovery. Precondition for the recognition of such a plant as replacement measure is a heat recovery rate of at least 70 %. (German Government, 2008 p. 17)

The use of a cogeneration unit is only accepted as such a measure, if the process of the unit is classified as “high efficiency cogeneration” in conformity with the European Directive 2004/8/EC, on which the evaluation is still based. (German Government, 2008 p. 17)

Energy saving measures are valid if the requirements of the EnEV (see 3.2 “Energieeinsparverordnung” – Energy Saving Regulation) are positively exceeded. The annual primary energy requirements as well as the mean heat transfer coefficient have to shortfall the reference values by 15 %. (German Government, 2008 p. 17) Therefore it makes sense to evaluate the situation regarding the EnEV before fulfillment of the REHA is analyzed.

Precondition for district heating or cooling to be counted as replacement measure in the sense of the REHA is that the heat in the district network originates partly from renewable energies, from plants for the use of waste heat or other replacement measures. The same obligatory shares like for own production are necessary. (German Government, 2008 pp. 6,18)

### 3.3.3 Application of the Renewable Energies Heating Act

All technologies, including RE as well as the replacement measures can be combined to fulfill the Renewable Energies Heating Act. (German Government, 2008 p. 6) Every alternative contributes a certain degree of fulfillment ($DF_i$). The latter can be obtained by the coverage ratio (CR) (actual share of the heat resulting from the technology compared to the total consumption of the system (AGFW, 2012 p. 6)) and the obligatory share (OS) and is calculated as follows.

$$DF_i = \frac{CR_i}{OS_i} \tag{7}$$

The overall degree of fulfillment of the system can be determined by the sum of the several degrees of fulfillment of the combined technologies. (AGFW, 2012 p. 9)

$$DF_{total} = \sum_i \frac{CR_i}{OS_i} \tag{8}$$

If one heating plant supplies different buildings with heat energy, the law can be met for all buildings in one extent. Alternatively, the system boundaries can be reduced to single facilities where every single system has to comply with the law separately. (German Government, 2008 p. 6)

Figure 12 summarizes the REHA. If the requirements cannot be met, the construction permit is refused.

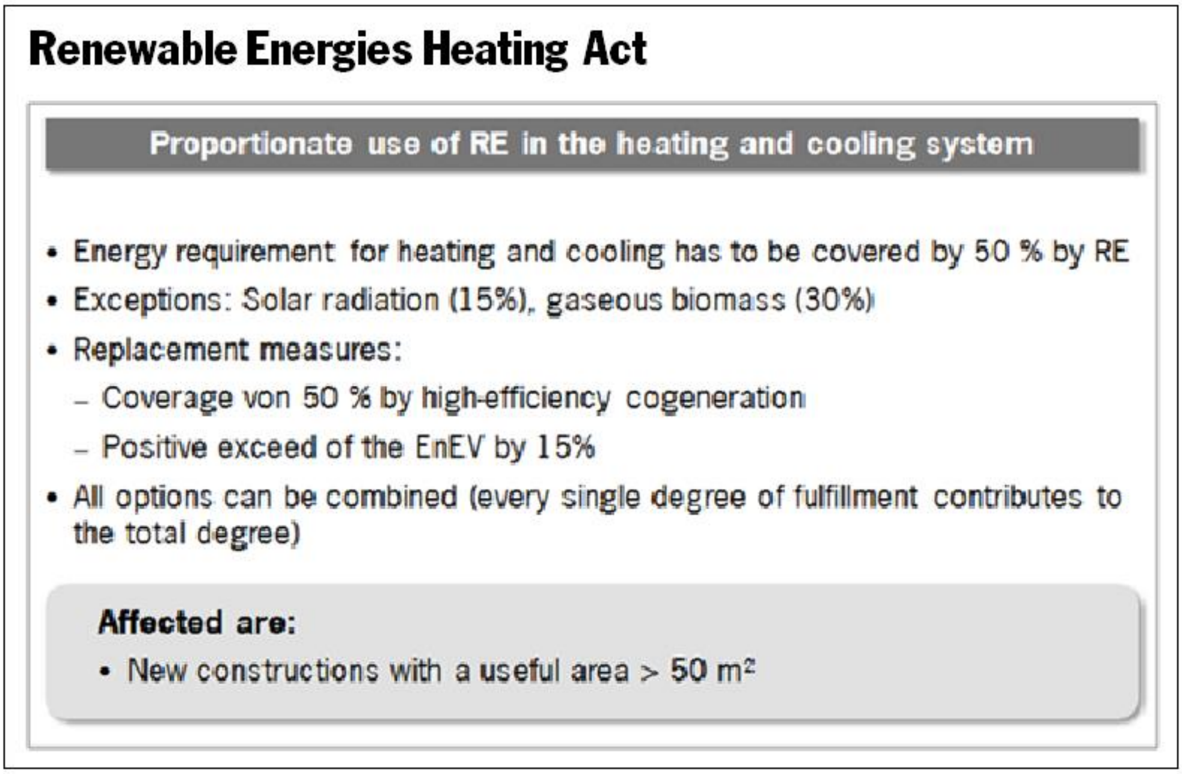


**Figure 12: Summary of the REHA for non-residential buildings, own design**

### 3.4 DIN V 18599

Like already mentioned in section 3.2.5 Application of the Energy Saving Regulation, the German standard DIN V 18599 is the base for the calculation of the energetic performance of buildings. It was adjusted in 2013 by DIN V18599 -5 Berichtigung 1 (Standardisation, 2013). An exact methodology for the determination of the primary and delivered energy requirements of a building for heating, cooling, ventilation, hot water and lighting are outlined. (German Institute for Standardisation, 2011) The standard is structured in 11 parts[1] (see also Figure 13).

**Part 1:** General balancing procedures, terms and definitions, zoning and evaluation of energy carriers
**Part 2:** Energy needs for heating and cooling of building zones
**Part 3:** Energy needs for air conditioning
**Part 4:** Energy need and delivered energy for lighting
**Part 5:** Delivered energy for heating systems
**Part 6:** Delivered energy for ventilation systems and air heating systems for residential buildings
**Part 7:** Delivered energy for ventilation systems and air heating systems for non-residential buildings
**Part 8:** Energy need and delivered energy for domestic hot water systems
**Part 9:** Delivered and primary energy for combined heat and power plants
**Part 10:** Boundary conditions of use, climatic data
**Part 11:** Building automation

[1] All parts are extracted from the German standard DIN V 18599 (German Institute for Standardisation, 2011)

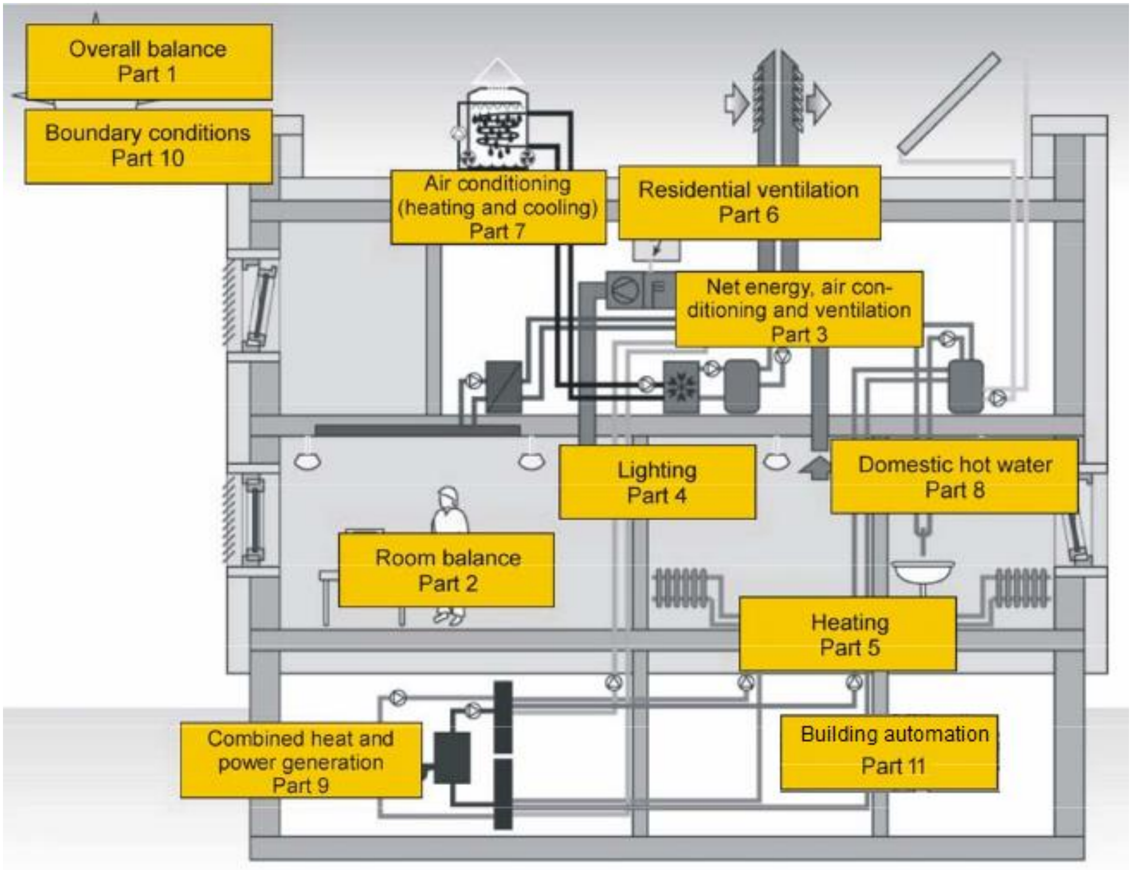


**Figure 13: Overview of the parts of DIN V 18599 adapted from (German Institute for Standardisation, 2011)**

This standard assigns a reference object with the same geometry and use to each building what enables a high comparability of different buildings regarding the Energy Saving Regulation.

## 3.5 Renewable Energy Sources Act - apportionment

The Renewable Energy Sources Act introduced in Germany supports the production of electricity by RE sources (e.g. subsidies, fixed feed-in-tariffs). In 2014 an amendment of the Act is released. The production of electricity by wind- or solar power, biomass and other plants is no longer subsidized with fixed feed-in-tariffs. Instead the produced electricity can be sold at the open electricity market and producers of RE receive a market premium. The latter is paid by the transmission system operators and consists of the difference between the fixed feed-in-tariff and the stock market price of the electricity. The additional costs (market premium) are distributed to the electricity consumers in form of the Renewable Energy Sources Act – apportionment that is included in the unit costs for electricity. Since the beginning of 2015 the apportionment is 6.17 Cent/kWh. Practically this means, that to the price of every kWh of electricity 6.17 Cents are added due to the subsidies for RE and the consumer carries these extra costs. (Federal ministry for economics and energy, 2015)

## 3.6 Consequences for companies

The legal development in Europe and Germany regarding energy efficiency in the building sector has also a huge impact for the locations of companies. The fulfillment of national laws and orders are precondition to building permissions for construction projects. That is the reason why especially production sites with a huge and permanently changing building stock are affected the most. The underlying location is such a production site. Therefore, this master thesis deals with its future strategic energy supply against the background of those laws.

# 4. The company

Due to the publication of this version of the thesis this chapter is reduced and the introduction of the company left out. Only the essential and necessary parts for the further work are presented.

## 4.1 The company

Information about the company is restrained in the public version of the master thesis.

## 4.2 The location

The location of the company is a production site where industry goods are produced. It covers a huge area with 5 different factory areas and more than 50 buildings.

### 4.2.1 Expansion

An enormous investment to increase the building stock immensely will be done and by that also the heat supply requirement increases.

## 4.3 Heat supply

The required room temperature in an office building of the company is 22°C and should be maintained according the regulations of the company. Also the room temperature in the production halls has to be kept in a certain range to provide a good work environment for the employees. The term heat supply refers to the provision of heat energy to ensure that temperatures. (Construction departement , 2013 p. 12) Cooling capacity does not belong into to the field of heat supply. The location is supplied with heat by different energy centers. One of them (the most important one) covers the heat demand for the majority of the factories. (Construction departement , 2013 p. 14)

To ensure the heat supply for all processes of the production that require heat energy the energy center has to be in operation at all points in time.

A map of the company site including the position of the heat supply center and its supply area is restrained in this version of the thesis.

### 4.3.1 The energy center

The energy center consists of a combined heat and power unit (put into operation in 2010) with a gas motor (see 2.1.1 Combined heat and power unit (CHP)) and six heating boilers in which gas or oil can be combusted. There are two peak boilers, whose operation point is more variable, to cover peak demand and four regular hot water boilers.

The energy center does not hold any components for cooling. For the adaption of heat consumption and heat production and to ensure a balanced operation (better efficiency) a buffer storage (heat storage with hot water) is used. (ASUE S. 5) Table 4 summarizes the technical components of the energy center.

**Table 4: Technical data of the energy extracted from internal documents of the company, own design**

| | CHP | Hot water boiler | Peak boiler |
|---|---|---|---|
| **Number of units** | 1 | 4 | 2 |
| **Fuel** | Gas | Gas/oil | Gas/oil |
| **Thermal power** | 1,804 $kW_{th}$ | max. 9,360 $kW_{th}$ | max.6,100 $kW_{th}$ |
| **Electric power** | 1,999 $kW_{el}$ | - | - |

The primary heating grid distributes the heat energy produced in the energy center, with water as heat carrier, in the heating grid to several buildings of the respective factories.

The plan of the heating grid cannot be published in this version of the thesis.

To avoid the formation of steam in the primary heating grid a pressure-maintaining station provides a constant over-pressure of 8.0 bar. Thus the water never falls below its vapor pressure and therefore only liquid water is in the grid.

At the final stage of the primary heating grid district heating substations are installed. They contain shell and tube heat which connect the primary and secondary heat grid. Using the temperature difference between the various grids to influence the amount of transferred heat, the heat exchangers are the control unit of the heat distribution. To the secondary heating grid the radiators and other heat consumers of the buildings are connected. (Construction departement , 2013 pp. 14-16)

The supply area of the energy center covers big parts of the location and contains further capacities for new constructions. In the following years several new buildings are planned to be included into this supply area.

In the next steps of this thesis the supply area with its energy center is examined concerning the legal framework of the energy performance of buildings.

## 4.4 The new production building (NPB)

In the location a new construction is in the planning stage and will be built within the next years. Its task is to provide production area for the mounting of the car bodies. (Architecture company, 2015 p. 13) In principle the building provides production halls for robots and office rooms. (Architecture company, 2015 p. 13) Of course also sanitary facilities and common lounges will be part of the building stock. The building will be at maximum 167 m long and 160.5 m wide containing a building area of about 15,511 m². (Architecture company, 2015 p. 8) New production area of about 58,500 m² will be provided on four different floors. (Planning company, 2015 p. 5)

The design draft of the new building is left out in this version.

The new production construction will be connected to the primary heating grid of the energy center. In the basement of the building two shell and tube heat exchangers (see 2.1.2 Heat exchanger) a heating capacity of about 3,000 kW each, will be installed. They form the interface between primary grid and the building. (Planning company, 2015 p. 22)

In the master thesis this building will be the case example (or case study) for further examinations of the location regarding the energy laws for buildings. A software called “Solar-computer” is used to calculate the heat requirements of the building and to compare them to the legal limits to check the compliance of the laws.

## 4.5 Consequences of the laws for the location

Obviously, also the building stock of the company is obligated to fulfill the guidelines of the laws regarding the energy performance of buildings (EnEV and REHA, see 3. Legislative base for the energy performance of buildings). Otherwise, the permission for new constructions is not received.

The energy saving measures, which are balanced in the EnEV, also contribute to the fulfillment of the REHA, therefore they should be examined first.

The guidelines concerning the heat transfer coefficient of the building envelope (see 3.2.2 Limits for the heat transfer coefficients) and summer heat protection (see 3.2.3 Summer heat protection) are simply issues that should be considered in the planning stage by the architects and civil engineers. They are implemented building-specifically.

The compliance of the limit for annual primary energy requirement (see 3.2.1 Limits for the annual primary energy requirement) however, can be crucially influenced. This energy requirements consists of energy consumption for heating and cooling, hot water, lighting, ventilation and cooling (see 3.2.1 Limits for the annual primary energy requirement). Of course a lot of processes can be examined and improved in their energy efficiency and measures to save energy can be implemented, but in the industry of car production to ensure a safe operation has priority. Therefore, in a lot of cases it is not recommendable to change well-functioning processes.

Another, more promising way of reducing the annual primary energy requirement is the improvement of the primary energy factor, which consists of the ratio between primary and delivered energy (see section 3.2.1 Limits for the annual primary energy requirement).

The electricity demand for cooling, air-conditioning and lightning is covered with energy supply from the public grid. The primary energy factor of electric power depends on the electricity mix, which represents the proportion of several producers (e.g. coal power plants and renewable producers). This factor cannot be influenced by the company as final consumer. The primary energy factor of the heat supply however, can be influenced, because the heat is produced locally and by the company's energy center. The energy for heating has a huge share in the balance of a company's overall energy consumption. That is the reason why the primary energy factor of the heating supply contains potential for the reduction of the energy requirement and is therefore examined in further steps of the thesis.

The primary energy factor of heating depends on the fuel that is combusted as well as the efficiency of the energy center. If no measurement is made and no certification executed a factor of 1.3 (see Table 5, "district heat from boilers – fossil fuel") is assumed for the combustion of fossil fuels. (AGFW, 2014 pp. 6,13)

**Table 5: Primary energy factors in Germany according DIN V, adaption of (AGFW, 2014 p. 13)**

| Energy carrier | | Primary energy factor $f_P$ |
|---|---|---|
| Fossil fuels | Fuel oil | 1.1 |
| | Natural gas | 1.1 |
| | Liquid gas | 1.1 |
| | Hard coal | 1.1 |
| | Lignite | 1.1 |
| District heat from CHP | Fossil fuel | 0.7 |
| | Renewable fuel | 0.0 |
| District heat from boilers | Fossil fuel | 1.3 |
| | Renewable fuel | 0.1 |
| Electricity | Electricity mix | 2.8 |
| Bio fuels | Bio- gas/oil | 0.5 |
| | Wood | 0.2 |
| Energy from the environment | Solar, geothermal, … | 0.0 |

Up to now the energy center (see 4.3.1 The energy center) of the company is not certificated. It consists of several boilers ($f_p$ = 1.3) and a combined heat and power unit ($f_p$ = 0.7, see Table 5, "district heat from CHP – fossil fuel"). (AGFW, 2014 p. 13) So far the building department of the company used a conservative estimation for the primary energy factor of $f_p$=1.10 for the planning.

In the next step of this master thesis the situation of the new production building concerning the laws regarding the energy performance of buildings is discussed. For that purpose the primary energy factor is varied and the effects analyzed. On that basis, conclusions for the whole supply area of the energy center are drawn.

## 4.6 Compliance of the laws - example new production building

In this section the situation of the new production building (see.4.4 The new production building (NPB)) regarding the energy laws for buildings is analyzed.

### 4.6.1 Energy Saving Regulation (EnEV)

The Energy Saving Regulation has a direct influence on the Renewable Energy Heating Act and is thus first checked. The software „Solar - Computer“ (Modul B55, Version 5.13.01) is used to evaluate the fulfillment of the laws regarding the energy performance of buildings. For that purpose the annual primary energy requirement can be determined. In this section the software delivers results for the energy requirements of the new production building under variation of the primary energy factor of the energy center (see 4.3.1 The energy center).[2] The results for the values 1.10 (actual planning figure of the building department), 0.97 and 0.90 of the primary energy factor are evaluated.

Figure 14 summarizes the results of all calculations[3].

A reference building with an identical geometry and use like the building that is examined is according to the EnEV including tightening 2016 not allowed to exceed a primary energy requirement of $\mathbf{W}_{p,max}$ = 87.39 kWh/m²a (calculations done after the DIN V 18599, see chapter 3.4 DIN V 18599). This value is composed of the electric primary energy requirement for lighting, ventilation, air conditioning (37.19 kWh/m²a) and the primary energy use for heating and hot water, which depends on the primary energy factor of the energy center.

Figure 14 demonstrates, that the limit for the primary energy requirement is exceeded with a primary energy factor of 1.10 (assumption of the company so far from estimating the weight between boilers and CHP unit, not calculated) and the EnEV is not fulfilled.

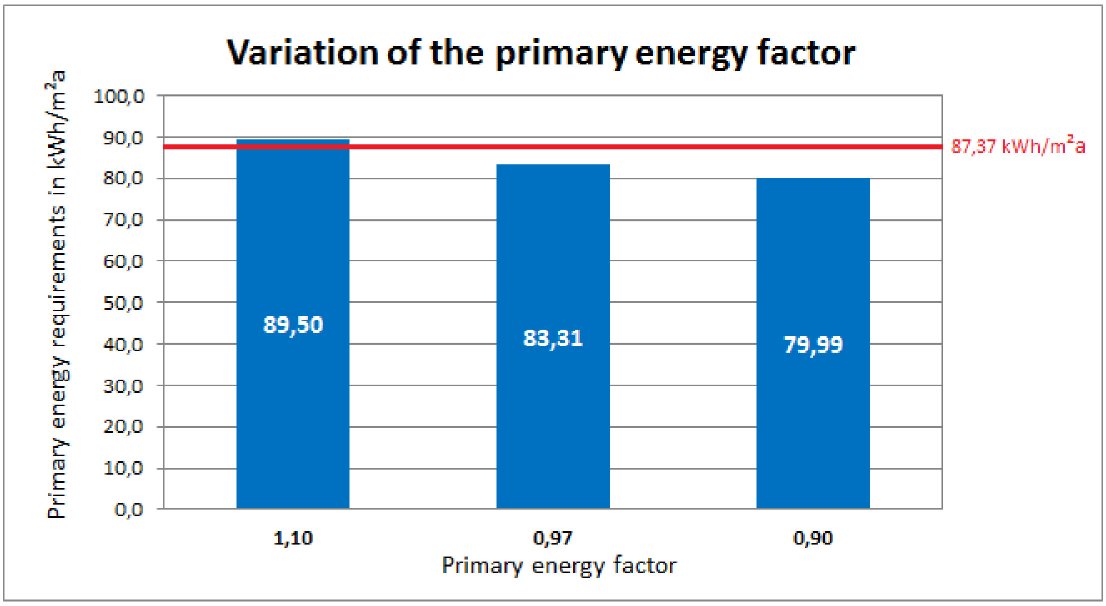


**Figure 14: Variation of the primary energy factor, own design**

[2] The calculations are executed by using the software „Solar - Computer“ (Modul B55, Version 5.13.01) and are erased from the appendix of this public version

For the factors 0.97 respective 0.90 the requirements can be met. A factor of 0.90 can even produce a shortfall of the limit.

The primary energy requirement for heating $\mathbf{W_{p,heat}}$ can be determined by the delivered energy $\mathbf{W_{del,heat}}$ and shows a proportional behavior regarding the primary energy factor. The primary energy use for electricity $\mathbf{W_{p,el}}$ is independent of this factor, therefore a linear mathematical relation between the total primary energy requirement $\mathbf{W_{p,total}}$ of a building and the primary energy factor $\mathbf{f_{p,FW}}$ of the energy center can be determined. Equation (9) delivers the exact mathematical relation.

$$W_{p,total} = W_{p,el} + W_{p,heat} = W_{p,el} + f_{p,FW} \cdot W_{del,heat} \quad \textbf{(9)}$$

### 4.6.2 Renewable Energies Heating Act (REHA)

The compliance of the REHA can also be examined by the application of the software „Solar - Computer“. The NPB serves as an example in that case, too. The fulfillment of the act is tested under the variation of the primary energy factor $\mathbf{f_{p,FW}}$ of the energy center.

The act obligates to cover a certain part of the energy (useable energy) for heating and cooling of a building with RE, otherwise resource-saving replacement measures have to be implemented. One option of the latter are energy saving measures (positive excess of the EnEV). The positive excess of the EnEV is related to the primary energy requirement (see 3.2.1 Limits for the annual primary energy requirement) and the heat transfer coefficient (see 3.2.2 Limits for the heat transfer coefficients). Both reference values have to be considered and the more critical value, which positively exceeds the limit less, delivers the coverage ratio (CR). If one of the criteria is not met, the EnEV is not fulfilled and can also not contribute to the REHA.

The contribution of this replacement measure in case of the NPB to the compliance of the REHA is depicted in Table 6. The heat transfer coefficients positively exceed the reference values with 8.6 % (opaque surfaces) respective 13.3 % (transparent surfaces). The primary energy requirements undercut its limits less in all the cases, therefore this criteria is responsible for possibility to cover the REHA by a positive excess of the EnEV. With a primary energy factor of the energy center of 1.10 the primary energy requirement is not met, therefore there is no contribution. Factors of 0.97 and 0.90 would deliver degrees of fulfillment of 31.0 % respectively 56.4 % (see Table 6 which summarizes the results obtained by the calculations with the software “Solar-Computer”).

**Table 6: Fulfillment of the REHA by positive excess of the EnEV, own design**

| Fulfillment of the REHA by positive excess of the EnEV | | | |
|---|---|---|---|
| **Primary energy factor** | **1.10** | **0.97** | **0.90** |
| Undercutting of the primary energy requirement | 0.0 % | 4.6 % | 8.5 % |
| Undercutting of the maximal value of the heat transfer coefficient | | | |
| … of opaque surfaces of non-residential buildings | | 8.6 % | |
| … of transparent surfaces of non-residential buildings | | 13.3 % | |
| Cover Ratio $\mathbf{CR}_{\mathbf{EnEV}}$ (minimal undercutting of one requirement) | 0.0 % | 4.6 % | 8.5 % |
| Obligatory Share $\mathbf{OS}_{\mathbf{EnEV}}$ | | 15.0 % | |
| **Degree of fulfillment** $\mathbf{DF}_{\mathbf{EnEV}}$ | **0.0 %** | **31.0 %** | **56.4 %** |

In total the energy requirement for heating and cooling of the new production building consists of the energy demand for space heating, hot water and the energy consumption of the ventilation for heating and cooling. In the ventilation system it is possible to recover heat (or cold) by air exchange, which can be regarded as a replacement measure ("Plants for the use of waste heat", see chapter 3.3.2 Replacement measures) to fulfill the REHA. The air exchange unit in the case of the NPB can, independent of the primary energy factor, cover 29.8 % of the energy requirement (delivered energy) for heating and cooling. With an obligatory share of 50 % for this measure it can deliver a degree of fulfillment of 59.6 %.

**Table 7: Fulfillment of the REHA under variation of the primary energy factor, own design**[4]

| Verification of the REHA | | | |
|---|---|---|---|
| **Primary energy factor** | **1.10** | **0.97** | **0.90** |
| Energy requirement for heating in kWh/a | | 2,340,502 | |
| Energy requirement for heating in the ventilation in kWh/a | | 1,452,661 | |
| Energy requirement for cooling in the ventilation in kWh/a | | 181,020 | |
| Energy requirement for hot water in kWh/a | | 236,551 | |
| Total energy requirement for heating and cooling in KWh/a | 4,210,735 | 4,210,734 | 4,210,734 |
| **Heat and cooling recovery in KWh/a** | | **1,255,336** | |
| Cover Ratio $\mathbf{CR}_{\mathbf{recovery}}$ | 29.8 % | 29.8 % | 29.8 % |
| Obligatory Share $\mathbf{OS}_{\mathbf{recovery}}$ | 50.0 % | 50.0 % | 50.0 % |
| **Degree of Fulfillment** $\mathbf{DF}_{\mathbf{recovery}}$ | **59.6 %** | **59.6 %** | **59.6 %** |
| **Positive excess of the EnEV – Degree of fulfillment** | **0.0 %** | **31.0 %** | **56.4 %** |
| **Total degree of fulfillment of the REHA** | **59.6 %** | **90.6 %** | **116.,0 %** |
| **Fulfillment of the REHA** | **no** | **no** | **yes** |

[4] The calculations are performed with the software „Solar - Computer" (Modul B55, Version 5.13.01) and are restrained in the public version of the thesis

Under the use of equation (8) the total degree of fulfillment can be calculated by the sum of the several components. With the value $\mathbf{f_{p,FW}}$ = 1,10 (used for planning inside the PAG) for the primary energy factor of the energy center the regulations of the REHA cannot be met.

With a primary energy factor in the area of 0,90 both laws concerning the energy efficiency of buildings could be easily met in case of the new production building.

However, it has to be mentioned, that this examination regarding the REHA does not consider the heat energy produced by the cogeneration unit in the energy center. A huge amount of buildings is supplied by the same heat grid, therefore it makes more sense to evaluate and adapt the whole system concerning the energy efficiency laws than distribute the renewable (or cogenerated) heat energy resources to single buildings. The latter could lead to difficulties in future construction projects, if all the potential resources are already used by single buildings. In the frame of this thesis a concept for the long-term fulfillment of the energy efficiency laws for buildings will be drafted. With this procedure, the expansion of the factory is easier to realize in the legal scope.

Consequently, the cogeneration unit is considered not here but in further steps of the concept development for the overall system.

### 4.6.3 Significance of the results for further building projects

All the considerations so far are based on the new production building. The results, however, can be transferred to other new buildings in the supply area of the energy center , because the application of DIN V 18599 (see 3.4 DIN V 18599) delivers reference values with a high level of comparability. This procedure enables that influencing factors like the primary energy factor of the heat supply have the same impact on different buildings in the supply area. This is the reason why the examination of the NPB delivers representative results for other new constructions, too.

Equation (9) can be transferred and the limit value for the primary energy factor to fulfill the criteria of the EnEV can thus be obtained:

$$f_{p,FW} = \frac{W_{p,max} - W_{p,el}}{W_{del,heat}} = \frac{87.37\,\frac{kWh}{m^2a} - 37.19\,\frac{kWh}{m^2a}}{47.55\,\frac{kWh}{m^2a}} = 1.06 \qquad \textbf{(10)}$$

In case of the NPB, supplied by the energy center, the requirements of the EnEV can be met with a primary energy factor $\mathbf{f_{p,FW}}$ of 1.06.

For the determination of the critical value for the primary energy factor to comply the renewable energy heating act, the degree of fulfillment DF of equation (8) has to be decomposed.

$$DF_{total} = \sum_{i} \frac{CR_i}{OS_i} = \frac{CR_{recovery}}{OS_{recovery}} + \frac{CR_{EnEV}}{OS_{EnEV}} \tag{11}$$

Under the use of equation (11) the necessary Cover Ratio $\mathbf{CR_{EnEV}}$ contributed by a positive excess of the EnEV to fulfill the REHA can be determined. The contribution of the recovery of heat and cold ($\mathbf{CR_{recovery}}$ = 29,8 %) by the ventilation has to be regarded, too.

$$CR_{EnEV} = \left(DF_{total} - \frac{CR_{recovery}}{OS_{recovery}}\right) \cdot OS_{EnEV} = \left(100\,\% - \frac{29.8\,\%}{50\%}\right) \cdot 15\,\% = 6.06\,\% \tag{12}$$

Consequently, in case of the NPB the EnEV has to be positively exceeded by 6.06 % to fulfill the REHA. The heat transfer coefficients as second component of the EnEV-limits undercut their limit in a higher percentage (8.6 % for opaque and 13.3 % for transparent surfaces) and are thus not the critical factor. Therefore, the impact of the primary energy factor is the essential influence. The annual primary energy requirement of the NPB has to undercut the reference value by 6.06 %, which corresponds to a consumption of 82.08 kWh/m²a.

Equation (13) shows the correlation for the determination of the Coverage Ratio of the contribution of the EnEV:

$$CR_{EnEV} = \frac{W_{p,max} - W_{p,total}}{W_{p,max}} = \frac{W_{p,max} - (\,W_{p,el} + f_{p,FW} \cdot W_{del}}{W_{p,max}} \tag{13}$$

With the conversion of equation (13) to equation (14) the required primary energy factor $\mathbf{f_{p,FW}}$ to meet all the standards of the laws can be obtained. The value is 0.94.

$$f_{p,FW} = \frac{W_{p,max} \cdot (1 - CR_{EnEV}) - W_{p,el}}{W_{del,heat}} = 0.94 \tag{14}$$

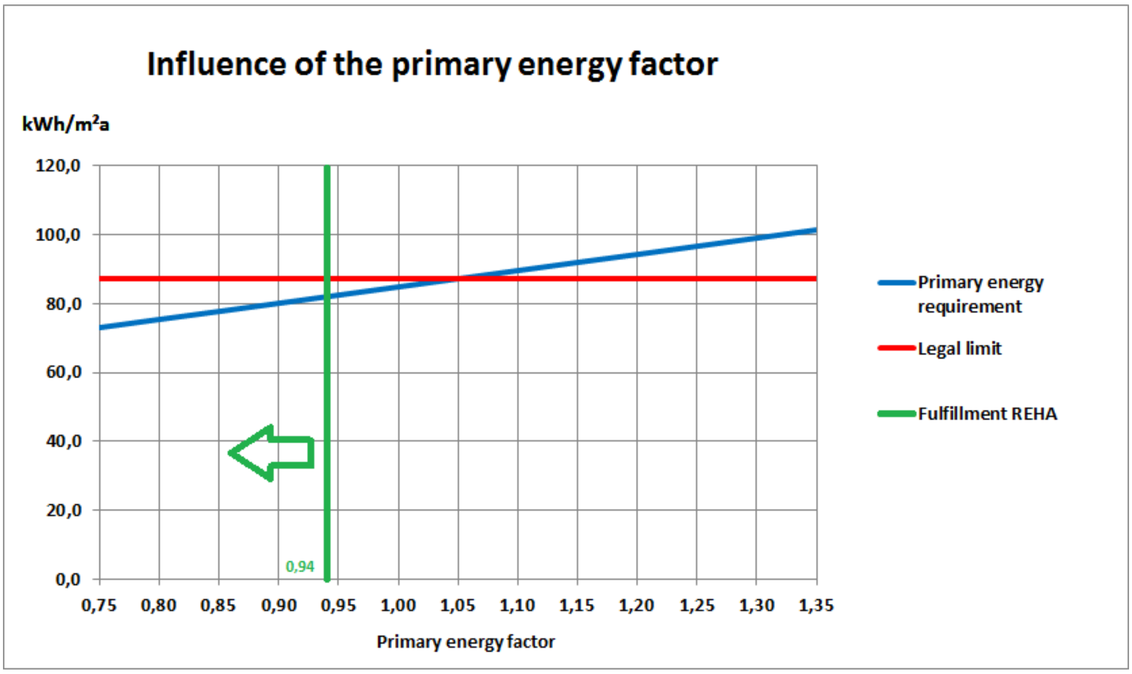


**Figure 15: Influence of the primary energy factor on the compliance of the energy laws, own design**

Figure 15 summarizes and illustrates the results of the last section examining the situation of the new production building. In its case the requirements of the Energy Saving Regulation can already be met with a primary energy factor $\mathbf{f_{p,FW}}$ (of the energy center) of 1.06. For the compliance of the REHA this value is not sufficient, a primary energy factor $\mathbf{f_{p,FW}}$ of 0.94 is necessary (actual planning value: $\mathbf{f_{p,FW}}$ = 1.10)

Having a high degree of comparability due to the DIN V 18599 (see 3.4 DIN V 18599), this result is a good indication for new construction projects as well. Although the comparability is very high, in every single project some deviation can occur. Therefore, the draft of the long-term concept should contain capacity for tolerance and the primary energy factor of the energy center should be in the area of 0.90 or smaller.

# 5. Assessment and improvement of the legal situation

In this chapter first of all the supply area of the energy center (see 4.3.1 The energy center) is assessed regarding the fulfillment of the national energy efficiency laws for buildings under the use of the results of the last chapter.

Fundamentally, in that process, it must be identified, which procedures for improvement exist that do not require any change in inventory (e.g. purchase of new components). Inventory neutral procedures do not imply investments in physical technical changes and have therefore to be considered first.

In the producing industry it is difficult to implement energy efficiency measures on the consumption side of the heat supply system, because a steady operation of the production processes has the first priority. The energy center is in operation since the year 2010 and has modern technical standards, so the benefit of efficiency measures is strongly limited. Consequently, the only reasonable inventory neutral procedure to reduce the primary energy consumption is the calculation of the real primary energy factor of the heat supply system (instead of still using the estimated value of 1.10), which is referred to as certification of the energy center (see Figure 16).

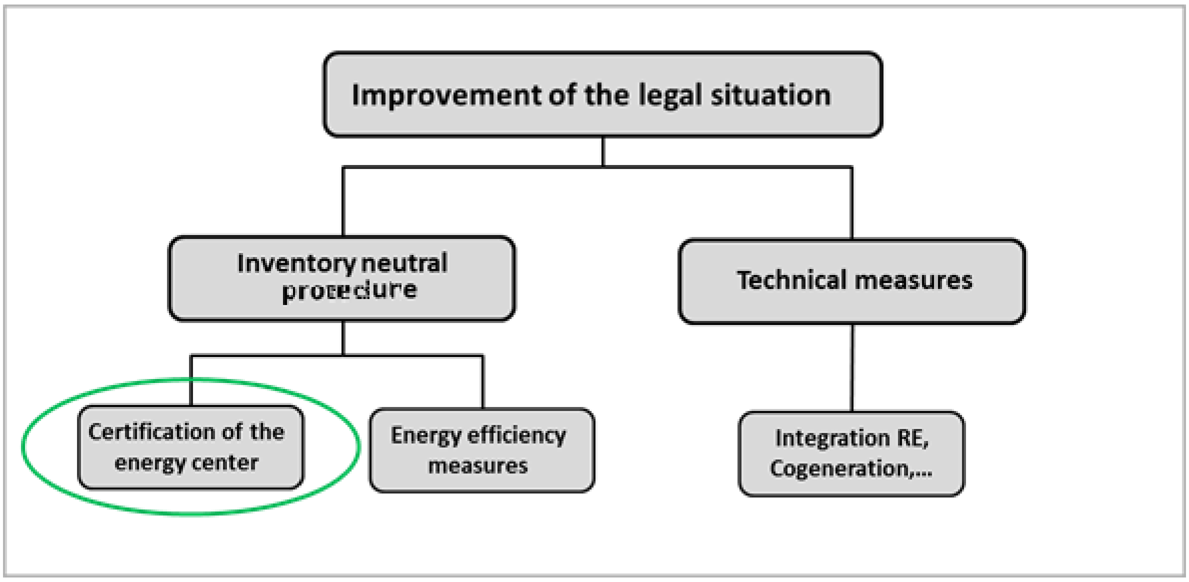


**Figure 16: Improvement of the legal situation, own design**

At the moment the planners of the company design their projects with a value of $f_{p,FW}$ = 1,10. With the certification the actual primary energy factor of the energy center (which has a huge impact on the legal situation regarding the fulfillment of the laws on the energy efficiency on buildings) is determined on the base of empirical data.

In the next section (5.1 Primary energy factor of the energy center) the empirical value for the factor is determined and its influence on the legal situation is checked.

## 5.1 Primary energy factor of the energy center

In the components of the energy center only fossil fuel (fuel oil or gas) can be combusted to produce heat energy (see 4.3.1 The energy center). The primary energy factors of several fuels (see Table 5) cover all expenditures and losses that occur during the extraction, processing, storage, transport and distribution of the fuels until they reach the system boundary of the energy center. (AGFW, 2014 p. 7)

In this section the primary energy factor $\mathbf{f_{p,FW}}$ of the energy center is determined on the base of the German worksheet AGFW FW 309 - Part 1 and standard DIN V 18599-1.

To calculate the primary energy factor of the heat supply system the system is modelled and the analysis is performed (see 2.5.1 Energy systems modelling by block diagrams) based on primary energy fluxes. Figure 17 represents the respective block diagram.

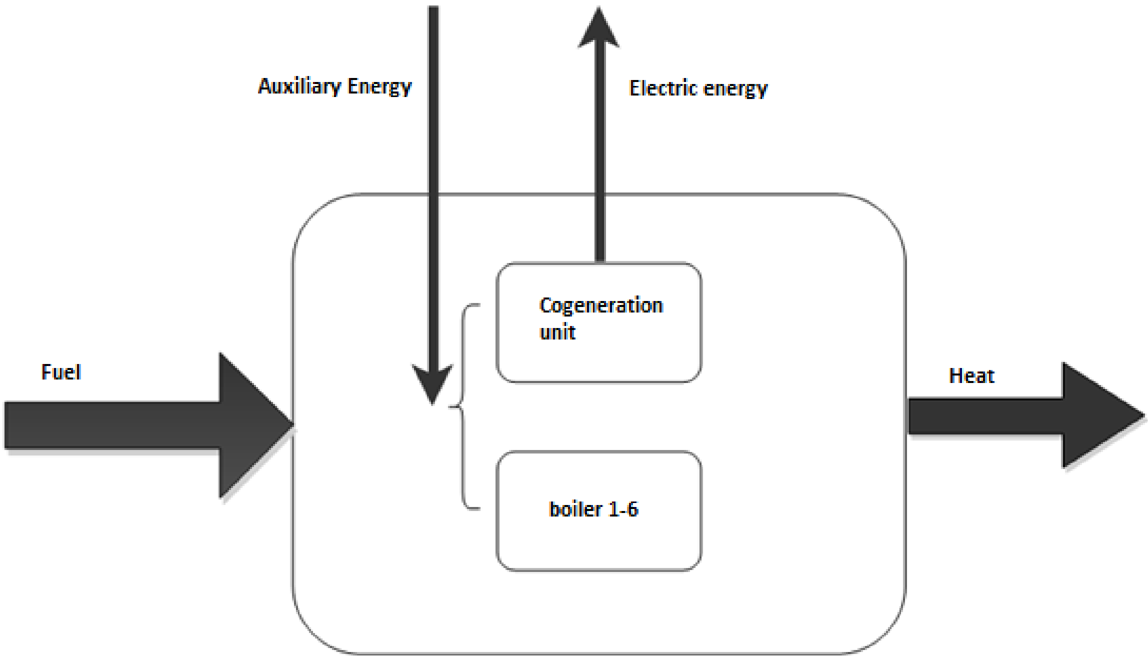


**Figure 17: Block diagram of the system energy center, own design**

For the energy center the following energy fluxes have to be considered (AGFW, 2014 p. 8):

- Inserted fuel $\mathbf{W_{Br,i}}$ (with regard to the lower heating value of fuel i) with its primary energy factor $\mathbf{f_{P,BR,i}}$
- Auxiliary energy $\mathbf{A_{HN}}$ (for the maintenance of the heat supply system, e.g. pumps) with the primary energy factor $\mathbf{f_{P,verdr}}$ of electric energy
- Produced eletric energy inside the system $\mathbf{A_{Bne,KWK}}$ by the cogeneratin unit with the primary energy factor $\mathbf{f_{P,verdr}}$ of electric energy
- Heat energy consumption $\mathbf{Q_{FW,j}}$ (measured on the primary side of the heat exchange unit of the supplied building j)

The primary energy factor $\mathbf{f_{P,FW}}$ of a heat supply system is determined by the specific energy consumption of the process based on equation (1). The combusted fuel, the auxiliary energy and the produced electric work by the CHP unit (also in consideration of the respective primary energy factor) are set in relation to the produced heat energy. (AGFW, 2014 p. 8) This approach delivers the equation (15).

$$\boldsymbol{f_{p,FW} = \frac{\sum_i W_{Br,i} \cdot f_{P,Br,i} + \left(A_{HN} - A_{Bne,KWK}\right) \cdot f_{P,verdr}}{\sum_j Q_{FW,j}}} \qquad \textbf{(15)}$$

To obtain meaningful results the guideline from the AGFW proposes to balance, if possible, all the data from the last three years. With that procedure temporal volatility of the system (changing climate conditions) and fluctuation in the production processes does not distort the outcomes. (AGFW, 2014 p. 8) For the energy center all the necessary data is accessible or can be derived from existing values.

**Table 8: Balance data of the energy center from 2012-2014, own design**

| Designation | 2012 | 2013 | 2014 | Total | Unit |
|---|---|---|---|---|---|
| **Fuel input** | | | | | |
| Natural gas – energy center total | 8,514,071 | 8,866,816 | 7,642,675 | 25,023,562 | $Nm^3$ |
| Natural gas – HHV ($H_o$) | 11.251 | 11.221 | 11.242 | 11.238 | $kWh/Nm^3$ |
| Natural gas – LHV ($H_u$) | 10.144 | 10.117 | 10.136 | 10.132 | $kWh/Nm^3$ |
| Natural gas – energy center total $H_o$ | 95,792 | 99,495 | 85,919 | 281,205 | $MWh_{Ho}$ |
| Natural gas – energy center total $H_u$ | 86,366 | 89,704 | 77,465 | 253,535 | $MWh_{Hu}$ |
| **CHP** | | | | | |
| Natural gas - CHP $H_o$ | 27,653 | 32,183 | 32,680 | 92,516 | $MWh_{Ho}$ |
| Natural gas s - CHP $H_u$ | 24,932 | 29,016 | 29,464 | 83,412 | $MWh_{Hu}$ |
| **Boilers** | | | | | |
| Natural gas - boilers 1-6 $H_o$ | 68,139 | 67,312 | 53,239 | 188,689 | $MWh_{Ho}$ |
| Natural gas - boilers 1-6 $H_u$ | 61,434 | 60,688 | 48,000 | 170,122 | $MWh_{Hu}$ |
| Fuel oil - boiler 1-6 | 140,284 | 5,879 | 8,227 | 154,390 | Litres |
| Fuel oil - boiler 1-6 $H_o$ (10,7 kWh/l) | 1,501 | 63 | 88 | 1,652 | $MWh_{Ho}$ |
| Fuel oil - boiler 1-6 $H_o$ (9,9 kWh/l) | 1,387 | 58 | 81 | 1,526 | $MWh_{Hu}$ |
| Fuel consumption - boiler 1-6 $H_o$ | 69,640 | 67,374 | 53,327 | 190,341 | $MWh_{Ho}$ |
| Fuel consumption - boiler 1-6 $H_u$ | 62,821 | 60,746 | 48,082 | 171,648 | $MWh_{Hu}$ |
| Fuel consumption $H_o$ - total | 97,293 | 99,557 | 86,007 | 282,857 | $MWh_{Ho}$ |
| Fuel consumption $H_u$ - total | 87,753 | 89,762 | 77,546 | 255,061 | $MWh_{Hu}$ |
| **Heat generation** | | | | | |
| CHP | 12,455 | 14,238 | 14,611 | 41,304 | MWh |
| Boiler 1- 6 | 57,151 | 52,189 | 39,489 | 148,829 | MWh |
| Energy center total | 69,606 | 66,427 | 54,100 | 190,133 | MWh |
| **Heat losses** | | | | | |
| Heat take over at building side | 65,372 | 62,037 | 50,099 | 177,508 | MWh |
| Heat losses in heat grid | 4,234 | 4,390 | 4,001 | 12,625 | MWh |
| Proportional heat losses | 6.08 | 6.61 | 7.40 | 6.0 | % |
| **Electric power generation** | | | | 0 | |
| CHP – gross electric work generation | 12,234 | 14,212 | 14,487 | 40,933 | MWh |
| CHP – own electric work consumption | -197 | -229 | -233 | -659 | MWh |
| CHP - net electric work generation | 12,037 | 13,983 | 14,253 | 40,273 | MWh |
| Energy center – own el. work cons. | 577 | 482 | 891 | 1,950 | MWh |
| Own electric consumption without CHP | 380 | 253 | 658 | 1,291 | MWh |
| **Efficiency** | | | | | |
| Energy Center $H_o$ | 83.52 | 80.51 | 78.71 | 80.92 | % |
| Energy Center $H_u$ | 92.60 | 89.30 | 87.30 | 89.73 | % |
| Boiler 1-6 $H_o$ | 81.62 | 77.17 | 73.15 | 77.31 | % |
| Boiler 1-6 $H_u$ | 90.43 | 85.56 | 81.02 | 85.67 | % |
| CHP $H_o$ | 88.57 | 87.69 | 88.32 | 88.19 | % |
| CHP $H_u$ | 98.24 | 97.26 | 97.96 | 97.82 | % |

Table 8 summarizes the essential balance and operating data of the energy center from 2012 to 2014 for the determining of the primary energy factor of the heat supply system.

The data of the natural gas input are extracted from the energy bills from the company's gas supplier for the location. The values of the consumption of fuel oil come from the internal meter readings of the company's maintenance department.

The amount of the generated heat that leaves the energy center is counted at its exit point (before the heat grid) and again at the interface of the primary and secondary heat grid (on the primary side of the heat exchanger). This enables the obtaining of the heat losses in the grid. In the calculation of the primary energy factor by equation (15) the second counting point (building side after primary grid) is considered and therefore the heat losses implicitly included.

The electricity generation of the CHP unit is recorded by an electric meter and can be read out. The auxiliary energy (or the own electric work consumption) corresponds to the energy consumption of the whole [5] deducting the energy consumption of the compressed air supply plant[6]. The latter is the only (not negligible) functional component in the building besides the heat supply components.

With the primary energy factor for natural gas and fuel oil (**$f_{P,Br,i}$ = 1.1**) and for electric energy (**$f_{P,verdr}$ = 2.8**), extracted from Table 5, for the balance period (2012-2014) a primary energy factor of **$f_{P,FW}$ = 0.97** for the heat supply system can be obtained by equation (15). The calculations are summarized in Table 9.

**Table 9: Determination of the primary energy factor, own design**

| **Determination of the primary energy factor** | | |
|---|---|---|
| **Factor** | **Symbol** | **Value** |
| Fuel input | $\sum W_{Br,i}$ | 255,061 MWh |
| Primary energy use in fuel | $\sum W_{Br,i} \cdot f_{p,Br,i}$ | 280,566 MWh |
| CHP – net electric work generation | $\sum A_{Bne,KWK}$ | 40,273 MWh |
| Primary energy generation by the CHP unit | $\sum A_{Bne,KWK} \cdot f_{p,verdr}$ | 112,764 MWh |
| Auxiliary Energy | $A_{HN}$ | 1,291 MWh |
| Primary energy for auxiliary energy | $A_{HN} \cdot f_{p,verdr}$ | 3,614 MWh |
| Produced heat energy (building side) | $\sum Q_{FW}$ | 177,509 MWh |
| **Primary energy factor** | $\mathbf{f_{p,FW}}$ | **0.97** |

The calculations are reviewed and certified by a technical inspection association. A certificate (restrained in this public version) validates this value for the primary energy factor, if no structural change of the system or its components is performed, until 16.04.2025. That value of 0.97 can be used for the planning of all construction projects in the supply area.

In conclusion, this rather obvious inventory neutral procedure could deliver an improvement regarding the legal situation.

[5] Read out from the building management system (BMS) based on the power data of the electric transformer upstream the building
[6] Read out from the building management system (BMS) based on the power data of the compressed air supply plant

## 5.2 NPB – the real situation including the use of waste heat

In this subsection the real situation ($f_{p,FW}$ = 0.97) of the new production building regarding the energy efficiency laws for buildings is analyzed and further technical circumstances of the NPB considered.

The NPB provides production area for production processes (see 4.4 The new production building (NPB)), where a lot of steps are automated. A high number of electricity users, for example welding robots, emit a lot of heat radiation. This type of heat is called "industrial waste heat" and emerges in processes which purpose is the production of goods. It is considered in the determination of the annual primary energy requirement and is included with a primary energy factor of $f_{p,FW}$ = 0.0 (AGFW, 2014 p. 11).

In the previous examinations of the NPB regarding the fulfilment of the energy efficiency laws (4.6 Compliance of the laws - example new production building) industrial waste heat is not considered, because these energy intense processes (e.g. welding robots) do not occur in the majority of the other buildings. Therefore, the calculation including this type of heat is not representative for a wide-ranged building stock and general statements cannot be made. In storehouses or logistic warehouses for example only negligible amounts of waste heat are produced.

Table 10 illustrates the state of affairs with the certified primary energy factor and the consequences of the inclusion of the use of waste heat in the calculations. The EnEV can be met with a factor $f_{p,FW}$ = 0.97 in both cases. The yellow marked values show the difference of the examination with and without the effect of industrial waste heat. The use of the waste heat (calculated by the heat losses of the machines multiplied with their operation time) reduces the primary energy requirement for space heating enormously (46.12 kWh/m²a respective 32.08 kWh/m²a, see yellow mark) and by that also the annual primary energy requirement. With that consideration ($f_{p,FW}$ = 0.97, waste heat) the EnEV-restriction of primary energy use can be undercut by 21.0 % (instead of 4.6 % without waste heat).

The legal limit of the primary energy requirement changes in the calculations performed with the software "Solar-Computer" with the consideration of the use of waste due to a difference in the plant technology of the reference building, which is configured to calculate a maximum reference value. However, the variation is very small (87.37 kWh/m²a respective 87.15 kWh/m²a) and can therefore be neglected.

**Table 10: EnEV – with and without waste heat, own design**[7]

| Verification EnEV 2014 with tightening 2016 ($f_{p,FW}$ = 0.97, all values in kWh/m²a) | | |
|---|---|---|
| **Waste heat consideration** | **No** | **Yes** |
| Delivered energy use for space heating | 43.52 | 43.59 |
| Delivered energy use for hot water | 4.03 | 4.03 |
| Total delivered energy for heating $W_{del,heat}$ | 47.55 | 47.62 |
| Primary energy for heating $W_{p,heat}$ | **46.12** | **32.08** |
| Primary energy – other consumers $W_{p,el}$ | 37.18 | 36.82 |
| Total primary energy consumption $W_{p,ges}$ | **83.32** | **68.90** |
| Proportion of heating | 55.4% | 46.6% |
| Legal limit of the reference building for primary energy $W_{p,max}$ | **87.37** | **87.15** |
| Proportional undercutting of the reference value | 4.6% | 21.0% |
| **Fulfillment EnEV 2014 with tightening 2016** | **yes** | **yes** |

With the certified primary energy factor the requirements of the EnEV can be undercut by 4.6 % without the use of waste heat. This value does not completely ensure the fulfillment of the REHA by a positive excess of the EnEV.

The reduction of the consumption of primary energy by the use of waste heat increases the degree of contribution of EnEV to the fulfillment of the REHA. The value for the minimal undercutting of the EnEV is now delivered by the opaque surfaces (8.6 %), what provides a degree of fulfillment for the REHA of 57.3 % (see Table 11).

**Table 11: Fulfillment of the REHA by a positive excess of the EnEV, own design**

| Fulfillment of the REHA by a positive excess of the EnEV ($f_{p,FW}$ = 0.97) | | |
|---|---|---|
| **Waste heat consideration** | **No** | **Yes** |
| Undercutting of the primary energy requirement | 4.6% | 21.0% |
| Undercutting of the maximal value of the heat transfer coefficient | | |
| … of opaque surfaces of non-residential buildings | 8.6% | |
| … of transparent surfaces of non-residential buildings | 13.3% | |
| Cover Ratio $CR_{EnEV}$ (minimal undercutting of one requirement) | **4.6%** | **8.6%** |
| Obligatory Share $OS_{EnEV}$ | 15% | |
| **Degree of fulfillment $DF_{EnEV}$ only by exceeding the EnEV** | **30.7%** | **57.3%** |

[7] The calculations are performed with the software „Solar - Computer“ (Modul B55, Version 5.13.01) and are restrained in the public version of the thesis

With the contribution of the use of waste heat to the degree of fulfillment, the requirements of the renewable energy heating act can already be met (DF = 124.1 %) with the actual primary energy factor of $f_{p,FW}$ = 0.97. Table 12 summarizes the calculations.

**Table 12: Fulfillment of the REHA with and without use of waste heat, own design[8]**

| Verification of the REHA | | |
|---|---|---|
| **Consideration of waste heat** | **No** | **Yes** |
| Energy requirement for heating in kWh/a | 2,340,502 | 1,936,652 |
| Energy requirement for heating in the ventilation in kWh/a | 1,452,661 | 1,452,732 |
| Energy requirement for cooling in the ventilation in kWh/a | 181,020 | 115,791 |
| Energy requirement for hot water in kWh/a | 236,551 | 236,551 |
| Total energy requirement for heating and cooling in KWh/a | 4,210,734 | 3,741,726 |
| **Heat and cooling recovery in KWh/a** | 1,255,336 | 1,251,252 |
| Cover Ratio $\mathbf{CR}_{\mathbf{recovery}}$ | 29.8% | 33.4% |
| Obligatory Share $\mathbf{OS}_{\mathbf{recovery}}$ | 50.0% | 50.0% |
| **Degree of Fulfillment** $\mathbf{DF}_{\mathbf{recovery}}$ | **59.6%** | **66.8%** |
| **Positive excess of the EnEV – Degree of fulfillment** | **30.7%** | **57.3%** |
| **Total degree of fulfillment of the REHA** | **90.3%** | **124.1%** |
| **Fulfillment of the REHA** | **no** | **yes** |

This subsection (5.2 NPB – the real situation including the use of waste heat) presents on one side the legal situation of the building with the real and certified primary energy factor, on the other side the effects of the use of industrial waste heat is examined. The latter is just included in the master thesis for the sake of completeness. For the development of a solution for the whole supply area this special case (use of waste heat) is not representative and will therefore not be taken into account in further steps of the concept draft in the framework of this work.

## 5.3 Energy Saving Regulation

The Energy Saving Regulation (see 3.2 “Energieeinsparverordnung” – Energy Saving Regulation) has three requirements for the construction of new buildings. On one side a limit for the annual primary energy consumption is set and on the other side it contains two requirements for the building envelope (heat transfer coefficient and summer heat protection).

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[8] The calculations are performed with the software „Solar - Computer“ (Modul B55, Version 5.13.01) and are restrained in the public version of the thesis

### 5.3.1 Present situation

The requirements of the EnEV regarding the building envelope have to be considered in the planning stage and solved constructively by architects or civil engineers, whereas the consumption of primary energy can be influenced in different factors. The most important one is the primary energy factor.

In chapter 4.6.3 Significance of the results for further building projects the calculations for the NPB regarding the compliance of the energy efficiency laws for buildings are executed and the meaning for further projects is derived. The EnEV can already be fulfilled with a primary energy factor of $f_{p,FW}$ = 1.06. With the actual value of $f_{p,FW}$ = 0.97 (see 5.1 Primary energy factor of the energy center) the law is positively exceeded by 4.6 %. The high level of comparability of the calculations based on DIN V 18599 (see 3.4 DIN V 18599) ensures a very high probability for further building projects in the supply area of the energy center to fulfill the law as well.

### 5.3.2 Opportunities for Improvement

Although the EnEV is not a big obstacle in receiving the building permit under the actual conditions, it makes sense to weigh up possible improvement measures, because a positive excess of the regulation contributes to the fulfillment of the REHA. To ensure this contribution the annual primary energy requirement has to be reduced. That can be realized in different ways. Building-specifically solutions, that can only be implemented in single projects, like the use of waste heat from welding robots, are not considered as a possible option. In the context of this thesis a holistic concept for the whole supply area is developed, not specific solutions for single buildings.

In the investigation of the heat supply system the further reduction of the primary energy factor of the energy center, that has already been discussed, represents a way to decrease the amount of required primary energy. By that effect the primary energy use for heating is lowered. This can be realized by the integration of several heat carriers or heat sources (e.g. bio-fuel or cogenerated heat) that possess low primary energy factors into the heat supply process or by efficiency measures concerning the heat supply system.

On the side of the electric consumption (lighting, ventilation and cooling) primary energy can also be saved by the own production of electricity inside the balance system. A photovoltaic system (see 2.2.1 Photovoltaic (PV)) could contribute in that way.

Figure 18 summaries the possible opportunities to improve the situation concerning the Energy Saving Regulation.

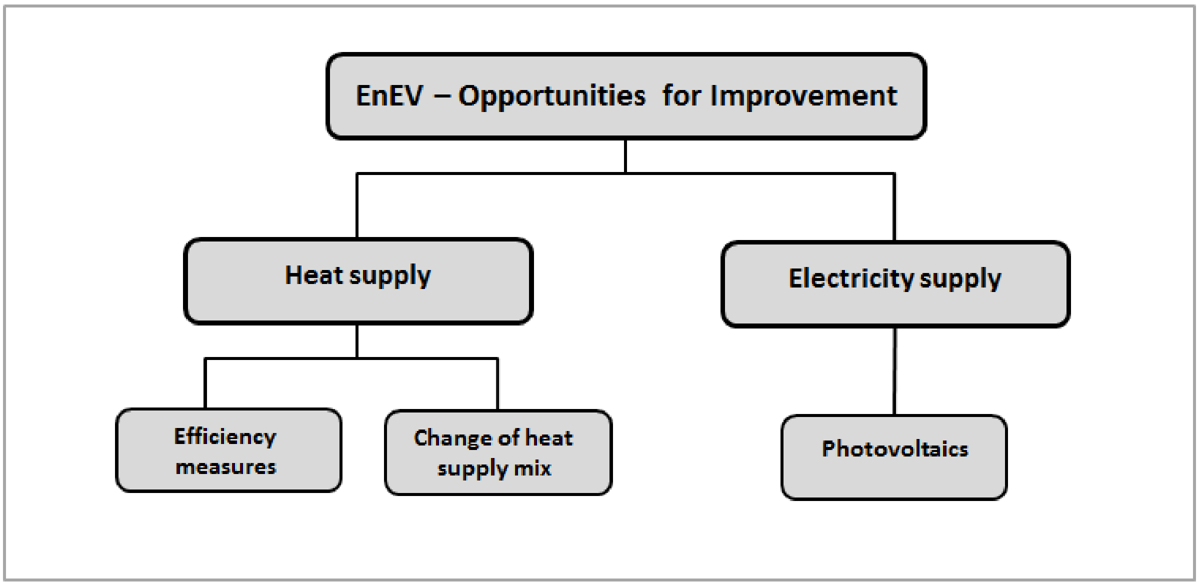


**Figure 18: EnEV -Opportunities for Improvement, own design**

## 5.4 Renewable Energies Heating Act

The already presented Renewable Energies Heating Act (see 3.3 “Erneuerbare-Energien-Wärmegesetz” – Renewable Energies Heating Act) obligates to integrate RE sources into the heat supply system of new constructions. Alternatively, replacement measures can be implemented.

### 5.4.1 Present situation

The REHA is, like the calculations in chapter 4.5 Consequences of the laws for the location demonstrate, a critical obstacle in receiving the construction permit.

In the case of the NPB the act cannot be met (isolated examination) with the actual primary energy factor of $f_{p,FW}$ = 0.97. The use of the industrial waste heat is not considered because of the presented reasons (see 5.2 NPB – the real situation including the use of waste heat). Heat and cooling recovery in the air exchange unit ($DF_{recovery}$ = 59.6 %) and the positive excess of the EnEV ($DF_{EnEV}$ = 30.7 %) deliver, according to equation (8), a total degree of fulfillment of $DF_{total}$ = 90.3 % (see 4.6.2 Renewable Energies Heating Act (REHA)). These components are building-specific. The calculations show, that the new production building (and therefore with a high probability also further projects) cannot fulfill the REHA if it is balanced as an own system.

Due to the high level of comparability, enabled by the application of the DIN V 18599, the results and tendencies of the evaluation of the building’s (case study) situation concerning the EnEV can be transferred to other buildings similarly. Little changes in this evaluation (EnEV) have huge effects on the compliance of the REHA (factor 100/15 $\approx$ 6.7) because of the value for the obligatory share of this replacement measure (15 %). Is the EnEV, for example, undercut by only 2.6 % instead of 4.6 % (coverage ratio decreases by 1 %), the degree of fulfillment, due to a positive excess of the EnEV, decreases from 30.7 % to 17.3 % (reduction of 13.4 %). This is the reason why the situation regarding the REHA (in contrast to the situation regarding the EnEV) of a building can only be transferred to another construction in a limited way.

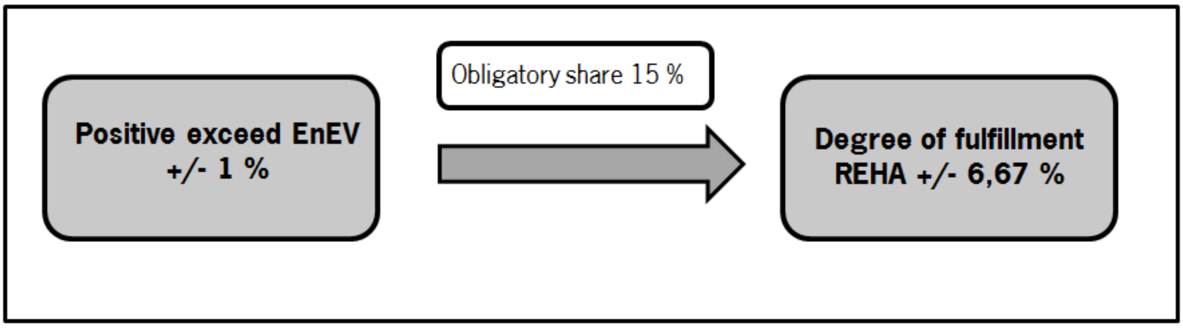


**Figure 19: Effect of the EnEV on the REHA, own design**

These are the reasons why the overall heat supply system with the energy center has to contribute to the compliance of the legal requirements as well. In the present constitution of the system only the CHP unit (as replacement measure) can deliver a coverage ratio with the precondition that the unit can be labeled as "high-efficiency cogeneration" in the sense of the European Directive 2004/8/EC. (Parliament, 2004) The Directive 2012/27/EU repeals the Directive from 2004, but the methodology to calculate the primary energy saving is still the same (Parliament, 2012 p. 31).This is investigated in the following part of the thesis by the use of the German worksheet "AGFW-Arbeitsblatt FW 308 – Zertifizierung von KWK-Anlagen" (certification of cogeneration units, (AGFW, 2011)).

**Approval of high-efficiency cogeneration**

According to the German worksheet a cogeneration unit is highly efficient, if the primary energy savings PES are bigger than 0.1 (CHP units with more than 1 MW nominal electric power). The primary energy savings PES can be calculated by equation (16):

$$PES = 1 - \frac{1}{\frac{(\frac{Q_{Bne,KWK}}{W_{KWK}})}{\zeta_{Ref,Q}} + \frac{(\frac{A_{Bbr,KWK}}{W_{KWK}})}{\zeta_{Ref,A}}} \quad (16)$$

$Q_{Bne,KWK}$ represents the quantity of heat production (41,394 MWh, see Table 8), $A_{Bbr,KWK}$ the gross electric work generation (40,933 MWh, see Table 8) and $W_{KWK}$ the fuel consumption (83,413 $MWh_{Hu}$, referring to the lower heating value see Table 8) of the CHP unit.

The reference value of electricity $\zeta_{Ref,A}$ can be obtained by equation (17) (AGFW, 2011 S. 68).

$$\zeta_{Ref,A} = (\zeta_{Ref,v} + \frac{k_k}{100})\, k_U \qquad \textbf{(17)}$$

The harmonized efficiency reference value for separate production of electricity $\zeta_{Ref,v}$ can be taken from Annex I of the official journal of the European Union establishing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council and repealing Commission Decision 2007/74/EC[9]. For natural gas (fuel of the CHP unit) and the CHP unit, put into operation in 2010, the reference value $\zeta_{Ref,v}$ is 52.50 %. (Comission, 2011).

The correction factor $k_k$ relating to the average climatic situation can also be extracted from the European journal (Annex III[9]). This factor is necessary to adapt the calculated efficiency under standard ISO conditions (15 °C) to the average annual temperature of the respective geographic position. For lower temperatures (Germany: annual average temperature in 2014 is 11.1 °C (Wetterkontor, 2015)) the efficiency increases under thermodynamic consideration by 0.1 % for each degree above 15 °C ambient temperature. Consequently, for the location a correction factor $k_k$ relating to the average climatic situation of 0.39 can be obtained. (Comission, 2011 p. 5)

The generated electricity of the CHP unit is exclusively fed into the electricity grid and with the respective voltage (0,4 – 50 kV) the correction factor for avoided grid losses $k_U$ is 0.945[9] (Comission, 2011 p. 6).

Using equation (17), the reference value of electricity $\zeta_{Ref,A}$ has the value 49.98 %.

The harmonized efficiency reference value for separate production of heat $\zeta_{Ref,Q}$ can be extracted from Annex II[9] of the official journal of the European Union. For the fuel natural gas and water as medium for heat transport the reference value is $\zeta_{Ref,Q} = 0.90$ (Comission, 2011 p. 6).

Inserting all these values in equation (16), a primary energy saving PES of the CHP unit of **34.78 %** (> 0.1) can be obtained. Consequently, the unit can be labeled as “high-efficiency cogeneration” in the sense of the European Directive 2004/8/EC and therefore it contributes (degree of fulfillment) to the fulfillment of the Renewable Energies Heating Act.

**Contribution of the CHP unit to the fulfillment of the REHA**

Labeled as “high-efficiency cogeneration” the CHP unit can cover a part of the REHA with its degree of fulfillment. In the balance period (2012 – 2014) the unit generates 41.394 MWh of heat (see Table 8), while the whole energy center (including also the boilers) produces 190.133 MWh heat (see Table 8) of heat energy (grid losses not considered). These values result in a coverage ratio $CR_{CHP}$ of 21,8 %.

[9] **Fehler! Verweisquelle konnte nicht gefunden werden.**The appendix contains all the utilized extracts of the uropean Journal

With the obligatory share $OS_{CHP}$ for cogeneration units of 50 % (see Table 3) the unit contributes (with an overall system approach) a degree of fulfillment $DF_{CHP}$ of 43,5 % (calculated with equation (7)).

Considering the contribution of the cogeneration unit (and $DF_{recovery}$ = 59.6 %; $DF_{EnEV}$ = 30.7 %), the new production has the following total degree of fulfillment $DF_{total}$ (see equation (18)) based on equation (8):

$$\boldsymbol{DF_{total}} = \sum_i \frac{\boldsymbol{CR_i}}{\boldsymbol{OS_i}} = \boldsymbol{DF_{CHP}} + \boldsymbol{DF_{EnEV}} + \boldsymbol{DF_{recovery}} = \mathbf{133.8}\,\% \quad \textbf{(18)}$$

Under the actual framework conditions the REHA in case of NPB can be met. Although the result is positive, if a closer look is taken, a long-term compliance of the laws cannot be assured. To proof that hypothesis, a possible expansion of the location is discussed against the background of the energy laws in the following part.

**Expansion of the location**

Like already explained (see 4.2.1 Expansion), a plan for the expansion of the company location exists. A huge investment in the building stock enables the construction of several new buildings. A lot of them can possibly be located inside the supply area[10] of the energy center and the heat requirement of the system will increase.

Considering a growth of the heat energy requirement for the supply area of 30 % (see yellow marking in Table 13), the boilers have to cover that increase as the CHP unit already works at nominal power. For that reason, the additional amount of heat energy has to be generated by the combustion in the boilers. Including their efficiency ($\eta_{boilers,Hu}$ = 85.67 %, see Table 8) to the calculations (and other data from Table 8), by equation (15) resulting from the energy system modelling, the respective primary energy factor $f_{p,FW}$ can be calculated. Table 13 illustrates the results of the calculation.

[10] Internal information of the company's construction department

**Table 13: Primary energy factor in case of expansion (+ 30 %), own design**

| | Existing system | Expansion |
|---|---|---|
| Fossil fuel consumption in MWh | 255,059 | 321,641 |
| Heat generation of the boilers unit in MWh | 148,829 | 205,869 |
| Primary energy factor of oil and gas | 1.1 | 1.1 |
| Electricity generation of the CHP unit in MWh | 40,274 | 40,274 |
| Heat generation of the CHP unit in MWh | 41,304 | 41,304 |
| Primary energy factor of electricity | 2.8 | 2.8 |
| Own electric consumption of the system in MWh | 1,291 | 1,678 |
| Primary energy factor of electricity | 2,8 | 2.8 |
| Total generated heat before grid losses in MWh | 190,133 | 247,173 |
| Total delivered heat consumption in MWh | 177,509 | 230,762 |
| **Primary energy factor** | **0.97** | **1.06** |

With this primary energy factor $f_{p,FW}$ = 1.06 the EnEV is just met but (see 4.6.3 Significance of the results for further building projects) cannot contribute to the fulfillment of the REHA ($DF_{EnEV}$ = 0.0 %) in case of the NPB. For other projects in the supply area even the compliance of the EnEV can be a significant obstacle.

The degree of fulfillment of the CHP unit decreases as well, because it has a smaller share on the overall heat generation (41304/247173 = 16.7 %). This causes the reduction of the degree of fulfillment from 43.5 % to $DF_{CHP}$ = 33.4 %.

With only the coverage shares of the CHP ($DF_{CHP}$ = 33.4 %) unit and the air exchange unit ($DF_{recovery}$ = 59.6 %) left, the application of equation (8) results in the following total degree of fulfillment:

$$DF_{total} = \sum_i \frac{CR_i}{OS_i} = DF_{CHP} + DF_{recovery} = 93.0\ \% \qquad (19)$$

This result proofs ($DF_{total}$ < 1), that the current inventory of heat supply does not ensure a long-term (including an expansion) compliance of the efficiency laws on the energy performance of buildings and therefore further opportunities for improvement have to be considered.

Comment: The cogenerated heat can also be included into the heat balance of single buildings. Consequently, for other construction less coverage capacity is available. This proceeding does not make a lot of sense in drafting a long-term concept for the heat supply system and is therefore no longer pursued in the frame of this thesis.

### 5.4.2 Opportunities for Improvement

In this subsection of the work all opportunities to improve the situation regarding the REHA are discussed and their feasibility is examined. The next chapter (6. Strategic energy supply - draft of the concept) contains the evaluation of the best of those options.

#### 5.4.2.1 Solar radiation

The integration of energy from solar radiation refers to the use of solar thermal power plants (2.2.2 Solar thermal energy),

Flat plate collectors, like described in section 2.2.2 Solar thermal energy, are only suitable for small scale applications. For the dimension of industrial factories they do not provide enough energy per surface.

The mounting of a reflecting mirror system to concentrate solar radiation (see 2.2.2 Solar thermal energy) is constructively a very difficult measure and has big impact on the structural design because of its heavy weight. On existing buildings, without any expensive modifications of the building structure, it is almost impossible to mount and originally not designed to be. Furthermore, such a system itself is already very expensive and not very effective in the German degree of latitude.

For these reasons the use of solar radiation to fulfill the REHA at the company location is not recommendable in a technical as well as economical view.

#### 5.4.2.2 Biomass

The energy center is composed of several boilers and a cogeneration unit. All the components are fed with fossil energy carriers (mainly natural gas) and put into operation in 2010 (high technological standards, no replacement needed). To combust liquid or solid biomass is not possible in the existing heat supply stock. The enabling of the combustion of gaseous biomass requires a tremendous and expensive system adaption as well. An alternative is the installation of a separate biogas plant (see 2.3 Biomass) to cogenerate heat and electricity (investment: about 4,000,000 €/$MW_{el}$ (Energieportal, 2015))

All those options produce very high costs that are disproportional to the benefit of fulfilling the laws.

#### 5.4.2.3 Geothermal energy and environmental heat

The possibility to integrate geothermal energy or environmental heat into the heat supply system of the location is eliminated by the criteria of „availability".

#### 5.4.2.4 Refrigeration from renewables

In the direct environment of the company location exist neither water reservoirs for cooling nor other useable RE sources, therefore this alternative can be excluded.

#### 5.4.2.5 Waste heat

Plants for the use of waste heat, like the heat recovery in the air ventilation unit are building-specific approaches. Drafting an overall concept for the energy supply in this thesis, this specific type of measure is not considered as a possible solution, but has to be considered if investigating the legal situation of a single building.

#### 5.4.2.6 Cogeneration

The energy center was renovated in 2010. Another change in the composition of the heating supply stock would cause enormous structural changes that require a relatively high investment. The acquisition of a CHP unit in general is a very cost-intense issue (about 3,800,000 €/$MW_{el}$ (Heizungsfinder.de, 2015)). From an economic point of view the investment in a new cogeneration unit is not recommendable.

#### 5.4.2.7 Energy saving measures (ESM)

Complying the regulations of the REHA by a positive excess of the EnEV constitutes an interesting opportunity (see 4.6.3 Significance of the results for further building projects). Savings of primary energy in small amounts can already have an enormous impact on the REHA (see Figure 19). Options for that are efficiency measures on the heat supply system, a change of the heat supply energy mix (reduction of the primary energy factor), the installation of a PV plant or building-specific measures like the improvement of the building insulation (choosing thicker walls during the planning stage).

Efficiency measures possess little potential as the energy center is relatively new (put into operation in 2010) and regularly serviced. The heat supply mix (combination of the heat sources and fuels) of the heat supply system can be modified with other measures listed in section 5.4.2 Opportunities for Improvement, therefore this aspect is not considered in this subsection.

The investment in a PV plant or in building-specific measures to reduce the primary energy requirement (positive excess of the EnEV) depicts a promising option for the fulfillment of the REHA. Therefore, those opportunities are considered in the further methodology of this thesis.

#### 5.4.2.8 District heat

The integration of district heat or cooling into the heat supply system is economically interesting, because the processes for the heat generation are located on the upstream side of the system. Therefore, all the cost-intensive components and machinery, as well as extensive constructive measures can be saved. Only a connection to the district heat grid is necessary.

During an analysis of the external conditions (see 5.5.1 SWOT-Analysis) it was discovered, that near the company location a biomass fermentation plant will be implemented. After contacting and negotiations with the public utility company, responsible for the biomass plant, the opportunity to purchase bio-district heat for the heat supply of the company location is offered. The delivered district heat has to be in accordance with the regulations of the REHA, what means to consist proportionally of RE or replacement measures. This alternative for improvement of the situation of the REHA is also discussed and evaluated in the following chapters.

#### 5.4.2.9 Summary

Figure 20 summarizes the results of this subsection and shows possible improvement measures on the legal situation concerning the Renewable Energies Heating Act.

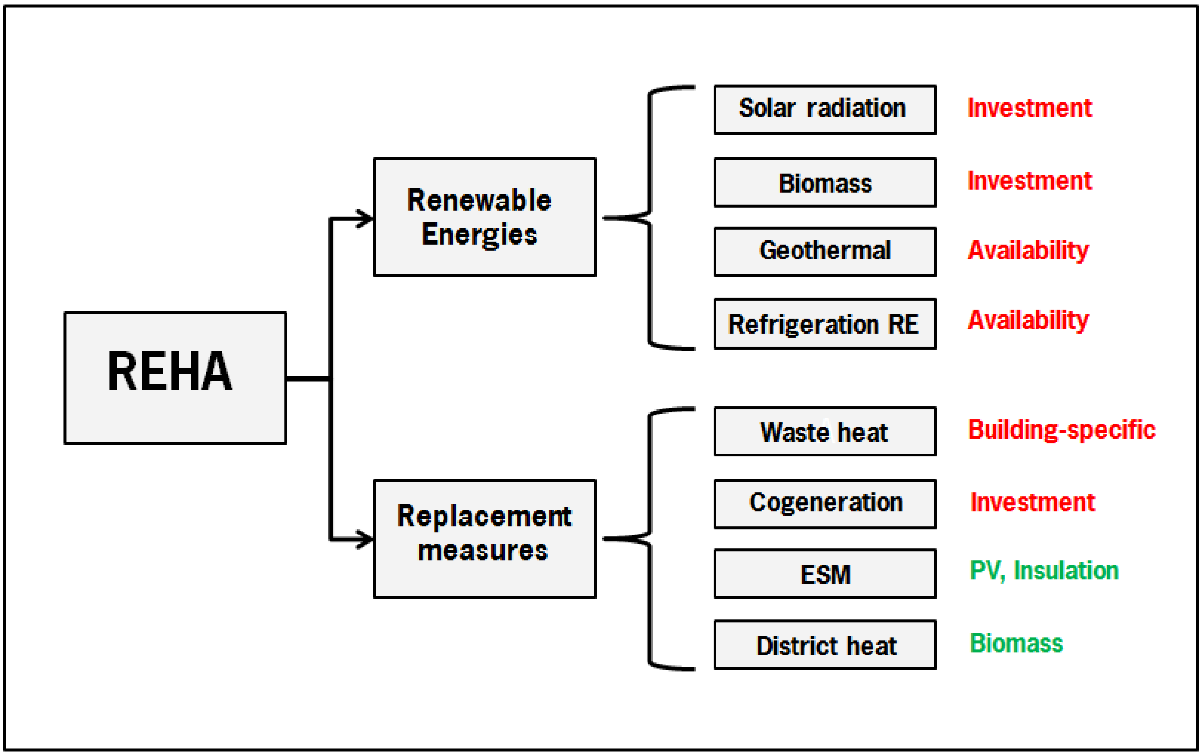


**Figure 20: REHA – Opportunities for improvement, own design**

## 5.5 Suitable alternatives

In this subsection possible strategies are identified to improve the situation regarding both energy laws (EnEV and REHA).

### 5.5.1 SWOT-Analysis

The underlying issue of the following SWOT-Analysis is the legal situation of the company site in regarding the laws on the energy performance of buildings.

Analyzing the internal conditions, a relatively high primary energy requirement of the buildings (see 4.6.1 Energy Saving Regulation (EnEV)), an energy center without integration of RE (see 4.3.1 The energy center) and limited space for an expansion of the building containing the energy center can be identified as weaknesses. Strengths are the existence of a CHP unit and PV plants (including the experience with those technologies) as well as a central heat supply system including all heat supply components (see 4.3.1 The energy center).

The external analysis is performed in the previous methodology of the thesis (see chapter 3. Legislative base for the energy performance of buildings and section 5.4.2 Opportunities for Improvement). The development of the laws on the energy performance of buildings can be seen as an external threat. With the obligation to introduce RE into the energy supply and a decreasing limit for the permitted primary energy requirement of a new building the regulations are tightened. The analysis of the legislative situation also delivers opportunities. Energy from renewable energies does not increase the requirement of primary energy ($f_p$=0.0, see Table 5) and therefore their integration can improve the legal situation significantly. Furthermore, the external analysis delivers information that a project of the city next to the production site of bio-waste treatment will be implemented (see 5.4.2 Opportunities for Improvement) and the opportunity for the company to purchase renewable heat energy exists.

**Table 14: SWOT-Analysis on energy laws for buildings, adapted from (Pelz, 2015)**

| | | External Analysis | |
|---|---|---|---|
| **SWOT-Matrix**<br>Energy laws for buildings | | **Opportunities**<br>- strong positive effect of RE in the legal framework<br>- existence of bio-district heat | **Threats**<br>- tightening legal requirements: Decreasing limit for primary energy requirement, Integration of RE |
| **Internal analysis** | **Strengths**<br>- existing CHP unit<br>- experience with PV plants<br>- central heat supply | **SO-Strategies**<br>- implementation of a PV plant<br>- include external RE (bio-district) energy source to the central heat supply | **ST-Strategies**<br>- implementation of a PV plant |
| | **Weaknesses**<br>- high primary energy requirement<br>- energy center without RE<br>- space limit of energy center | **WO-Strategies**<br>- include external RE (bio-district) energy source to the central heat supply | **WT-Strategies**<br>- improve insulation to meet the limit for primary energy requirement |

The SWOT-Analysis finally delivers three different strategies. The implementation of a PV plant is a SO-strategy that combines external opportunities with internal strengths (optimal case) as well as a ST -strategy.

Including an external RE energy source in form of bio-district heat is another SO-strategy which can combine the positive aspects of the external and internal analysis. Furthermore, it is a WO-strategy that can transfer weakness to strength.

The third identified strategy is the improvement of the insulation to reduce the primary energy requirement. By that WT-strategy the internal weakness is reduced to limit the effect of the external threat.

In conclusion, there are only three suitable technical measures for the improvement of the legal situation of the supply area of energy center under the actual framework conditions. They are further discussed and evaluated in the next chapter (6. Strategic energy supply - draft of the concept).

# 6. Strategic energy supply - draft of the concept

In this chapter a sustainable concept for the strategic energy supply of the company location is drafted. For this purpose all suitable options (see 5.5 Suitable alternatives) are compared and evaluated regarding their benefit and their costs.

## 6.1 Implementation of a PV plant

By the use of a photovoltaic plant (see 2.2.1 Photovoltaic (PV)) electric energy can be generated inside the system borders and therefore balanced as own production. The effect of this measure on the situation regarding the energy efficiency laws for buildings and the required investment are discussed in the next subsections of this master thesis.

### 6.1.1 Framework conditions

The implementation of a PV plant requires space and (in case of the mounting on the roof of a building) the necessary structural design to stand its weight (building-integrated photovoltaics are not considered in this thesis, but could be included in further investigations). This is the reason why the mounting of a PV unit is not possible on the roof of every building (without an enormous investment in the structure of the respective building).

Furthermore, the actual/realized value can, because of the change of framework conditions while the construction process, differ immensely from the nominal value of the PV-area from the planning stage (in which the buildings are already adapted to the compliance of the laws). An example for that case is a previous construction project of the company.[11] The actual area that is implemented is about half (2 $MW_p$) of the nominal area (4 $MW_p$). Consequently, if the nominal value is necessary for the fulfillment of the energy efficiency laws for buildings, they cannot be fulfilled in reality.

The company already possesses knowledge and know-how about this technology as some PV plants already exist.

The implementation of a PV plant is a building-specific measure to comply the laws, because the plant has to have a spatial link with the respective building.

Since the introduction of the system stability order (“Systemstabilitätsverordnung”) in 2012 the grid operators must be able to shut down PV plants by a control unit (power inverter) to maintain the supply security of the system. (protection, 2012) This increases the costs for the system’s technology.

In addition, all operators of a PV plant have to pay for the electric grid connection. (Photovoltaik.org, 2015)

[11] The description of the project cannot be published.

### 6.1.2 Effect on the energy laws

Due to the own generation of electricity by a PV plant, the consumption of delivered energy of a building (in terms of the EnEV) can be reduced as the electric work can be balanced inside the system. Preconditions for the integration in the balance system are a spatial link to the building as well as the usage inside the building (only excessive energy can be fed into the public grid). (German Government, 2013 p. 9)

This has a positive effect on the primary energy requirement of a building and therefore facilitates the fulfillment of the EnEV.

**EnEV - example NPB**

Calculations concerning the compliance of the EnEV for the new production building with a PV plant area of 2,500 m² on the roof of the building are available.[12] The own production of electric work reduces the delivered energy requirement of electricity consumers and therefore, considering the primary energy factor for electricity, also the primary energy requirement of the building. A PV area of 2,500 m² decreases the primary energy requirement of the NPB about 8.43 kWh/m²a. With that reduction and the primary energy factor of the energy center ($f_{p,FW}$ = 0.97) the EnEV can be undercut by 14.5 %. Table 15 summarizes all the calculations.

**Table 15: Calculation of the EnEV with a PV plant, own design**

| **Verification EnEV 2014 with tightening 2016** ($f_{p,FW}$ = 0.97, all values in kWh/m²a) | | |
|---|---|---|
| **PV plant (2500 m²)** | **No** | **Yes** |
| Delivered energy use for space heating | 43.52 | |
| Delivered energy use for hot water | 4.03 | |
| Total delivered energy for heating $W_{del,heat}$ | 47.55 | |
| Primary energy for heating $W_{p,heat}$ | 46.12 | |
| Delivered energy – other consumers $W_{del,el}$ | 20.60 | 15.80 |
| Primary energy – other consumers $W_{p,el}$ | 37.19 | 28.56 |
| Total primary energy consumption $W_{p,ges}$ | **83.31** | **74.68** |
| Proportion of heating | 55.4% | 61.8% |
| Legal limit of the reference building for primary energy $W_{p,max}$ | **87.37** | |
| Proportional undercutting of the reference value | 4.6% | 14.5% |
| **Fulfillment EnEV 2014 with tightening 2016** | **yes** | **yes** |

[12] The calculations are performed with the software „Solar - Computer" (Modul B55, Version 5.13.01) and are restrained in the public version of the thesis

**REHA - example NPB**

By the implementation of the PV-plant the annual primary energy requirement of the building can be reduced by 14.5 %. However, the EnEV-limits can only be undercut by 8.6 % ($DA_{EnEV}$) due to the heat transfer coefficient of opaque surfaces (see 4.6.2 Renewable Energies Heating Act (REHA)). This equals, with an obligatory share $OS_{EnEV}$ of 15.0 %, a degree of fulfillment of 57.3 %.

On the REHA (regulating a proportion of RE in the heat supply system) itself the measure PV has no direct influence, as the electricity from PV does not contribute directly to the heat supply.

**Summary**

The implementation of a PV plant is a building-specific measure to reduce the primary energy requirement of a building and therefore influences the EnEV in a positive way. The latter can contribute to the compliance of the REHA. A direct influence of the PV plant regarding the Renewable Energies Heating Act is not given (see Figure 21).

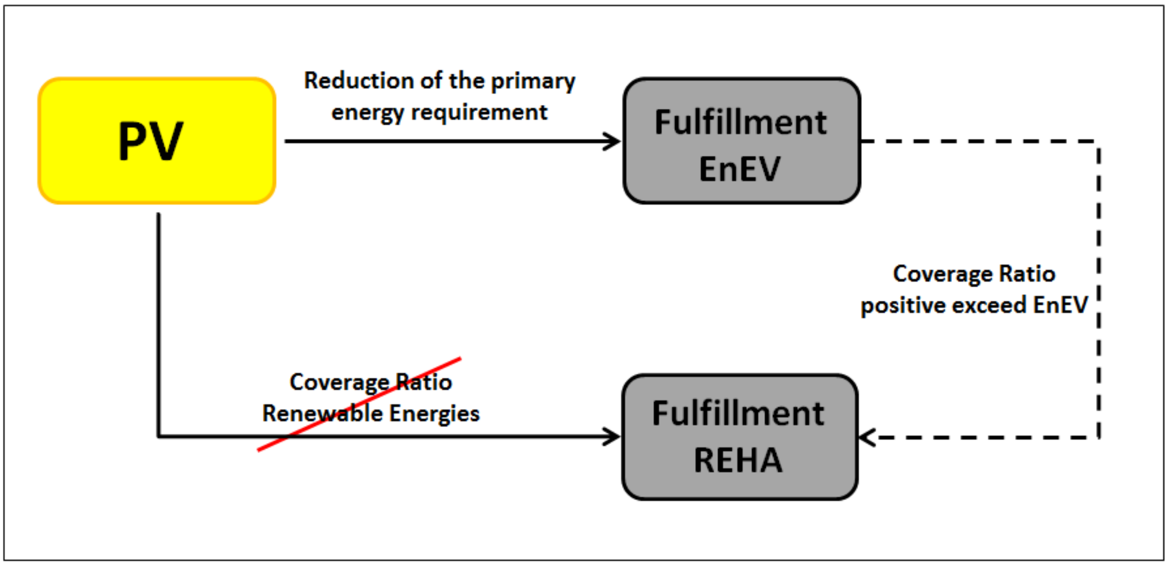


**Figure 21: Effects of a PV plant on the energy laws for buildings, own design**

If the PV plant is implemented in a sufficient scale (not possible for all buildings), both energy efficiency laws for buildings can be fulfilled with a high probability.

### 6.1.3 Investment appraisal

The company cooperates with a certain company in the solar sector if it comes to projects including photovoltaics. After requesting specific prices from the company the following data[13] for the implementation of a PV plant is given (Table 16):

[13] The request is answered on 06.08.2015 by the managing director of the solar company via E-Mail with the given data

**Table 16: Costs for the implementation of a PV plant, own design**

| Matter of expense | Value and unit |
|---|---|
| Grid connection | 50,000 € |
| PV module | 0.5 €/$W_p$ |
| System technology | 0.7 €/$W_p$ |

The grid connection costs, like already explained, emerge by the installation for the connection to the public electricity grid and the system technology contains all further components (high technical requirements due to the system stability order). Investment in measures concerning the building structure (static equilibrium) is not considered.

On the roof of an existing building of the company a PV plant was installed and put into operation in 2013. Table 17 gives an overview about the characteristics of this plant.

**Table 17: Data of the PV plant, own design[14]**

| | |
|---|---|
| Installed power | 240.24 $kW_p$ |
| Installed area | 1,837 m² |
| Generated annual work[15] | 234.9 MWh |

The discussed PV plant covers an area of 2,500 m². By the use of Table 17 (proportional transfer) this area has an installed power of 326.95 $kW_p$ and generates 319.68 MWh of electric work per year.

With module and system technology costs of 0.5 €/$W_p$ respectively 0.7 €/$W_p$ and grid connection costs of 50,000 € the overall investment $I_{PV}$ results in 442,340 € for a plant having the installed power of 326.95 $kW_p$.

This investment confronts positive cash-flows due to the own generated electric work. The price for electricity of 0.1725 €/kWh[16] deducting the proportionate apportionment of the Renewable Energy Sources Act (full amount of the apportionment: 0.0617 €/kWh, see 3.5 Renewable Energy Sources Act - apportionment) can be saved for every produced unit of energy.

For the own generation and direct consumption of electricity (in case of RE like PV) outside the feed-in tariffs, a proportionate apportionment has to be paid since 2015 (see 3.5 Renewable Energy Sources Act - apportionment) to carry the overall costs of the incentives for renewable energies. In the first year

[14] The data is descended from the mentioned former project appraisal of a PV-plant. It is left out in the public version.
[15] The generated work refers to the year 2014
[16] Current price the company pays for electricity to the electricity provider

the share is 30 %, in 2016 it is 35 % and for all further years 40 % (0.0247 €/kWh). (DIHK - German day of industry and chamber of commerce, 2015)

Table 18 contains all values for positive cash-flows as consequence of the investment in a PV plant. The project NPB is still in the planning stage, so the PV plant could not be put into operation before 2017 and therefore a proportionate apportionment of 40 % has to be paid.

**Table 18: Positive cash-flows due to own generation of electricity, own design**

| | |
|---|---|
| Electricity price[17] | 0.1725 €/kWh |
| Full apportionment | 0.0617 €/kWh |
| Proportionate apportionment | 0.0247 €/kWh |
| Generated annual energy | 319.68 MWh |
| Positive annual cash-flow[18] | 47,249 € |

Combining equation (2) and (4) of this thesis the net present value $NPV_{PV}$ of this alternative can be determined 8 (see equation (20)).

$$\boldsymbol{NPV_{PV} = -442,340\,€ + 47,249\,€ \cdot \left[\frac{(1+0.08)^{15}-1}{0.08 \cdot (1+0.08)^{15}}\right] = -37.913\,€} \qquad \textbf{(20)}$$

The project period n is 15 years and the interest rate of the company for investment appraisals is 8 %. Using equation (3) the measure has a payback-period of 17.96 years. Table 19 summarizes all calculations regarding the investment appraisal of a PV plant.

[17] The electricity price varies and is not constant over time. It depends on a lot of factors and forecasts are very difficult to make. The latter exceed the frame of this thesis, therefore the current price for electricity is used for the calculations.
[18] The positive cash-flows are calculated on the base of the electric work generated in 2014

**Table 19: Calculation NPV, own design**

| Term | Value | Unit |
|---|---|---|
| Investment – Implementation of a PV plant | - 442,340 | € |
| **Total investment** | **- 442,340** | **€** |
| Generated annual electric work | 319. 68 | MWh/a |
| Electricity price | 0.1725 | €/kWh |
| Proportionate apportionment | 0.0247 | €/kWh |
| **Annual saving due to own generation** | **47,249** | **€/a** |
| Nominal annual interest rate | 8.00 | % |
| Project period | 15 | a |
| **$NPV_{PV}$** | **- 37,913** | **€** |
| **Payback period** | **17.96** | **a** |

## 6.2 Purchase of bio-district heat

At the location the possibility of purchasing bio-district heat for the heat supply exists. This alternative is presented in the following subsection and its effect on the energy efficiency laws for buildings is examined. Finally, an investment appraisal is performed.

### 6.2.1 Framework conditions[19]

A public utility company of the city (next to the company location) is planning the installation of a biomass fermentation plant (see 2.3 Biomass) in close proximity to the company location. All the bio-waste of the households of the area is collected and disposal fees charged. The public utility company uses the biogas and converts it in a cogeneration unit into “green” electricity and heat. These products are distributed by the utility company.

The result of the negotiations with the public utility company is the possibility at the production location to buy the whole amount of generated heat (Annual work: 7,600 MWh, medium annual power: 867.6 kW) by the cogeneration unit at predetermined conditions and integrate them into the heat grid fed by the energy center.

The public utility company is responsible for planning, construction, investment, maintenance and operation of a district heat pipe utilizing the medium water to the company grounds of the company. On the company grounds the public utility company hands over the heat at predefined conditions (building cost subsidy, basic price and work price) to company. The integration of the bio-heat into the heat grid (connection to energy center), the installation and connection of the heat transfer station is the responsibility of the production company.

[19] The information and data are descended from agreements between the project partners during the negotiations

The graphical illustration of the project including a draft of the heat grid between the fermentation plant and the company site are restrained in the public version of the thesis.

The integration of the hot water (carrying the bio-heat) from the heat pipe of the public utility company into the heat supply system of company is realized by a heat exchanger. The hot water is fed into the return flow of the heat grid to elevate its temperature level.

### 6.2.2 Effect on the energy laws

The planned annual amount of available bio-heat $Q_{Bio,a}$ is 7,600 MWh. For the balance period from 2012-2014 ($Q_{Bio}$ = 7,600 MWh · 3 = 22,800 MWh) this is a share of 12.0 % of the overall heat consumption (190.133 MWh) of the building stock in the underlying heat supply system. The bio-heat produced in the CHP unit of the public utility company possesses, according Table 5, a primary energy factor of $f_{p,Bio}$ = 0.0 (“district heat from CHP - renewable fuel”).

**Primary energy factor**

Being connected to the return flow to the energy center, the bio-heat directly influences the primary energy factor of the heat supply system by reducing the fossil fuel consumption $\mathbf{W_{Br,i}}$ (see Table 20, yellow marking) and introducing bio-heat with a primary energy factor of “zero”. Table 20 (with data extracted from Table 8) proves this statement on the base of equation (15) (resulting from the energy system modelling) for the balance period from 2012 to 2014. The requirement of heat energy generation by fossil fuels by the boilers 1-6 (the CHP unit always runs at nominal power) decreases and by that also the consumption of fuel under consideration of the efficiency of the boilers ($\eta_{boilers,Hu}$ = 85.67 %, see Table 8). On that base the fuel consumption $W_{Br,\ new}$ including bio-heat is calculated in equation (21).

$$\boldsymbol{W_{Br,new} = W_{Br,old} - \frac{Q_{Bio}}{\eta_{Heiz}} = 255{,}059\ MWh - \frac{22{,}800\ MWh}{0.8567} = 228{,}445\ MWh} \qquad \textbf{(21)}$$

**Table 20: Primary energy factor including bio-heat, own design**

| | **Existing system** | **With bio-heat** |
|---|---|---|
| Fossil fuel consumption in MWh | 255,059 | 228,445 |
| Primary energy factor of oil and gas | 1.1 | 1.1 |
| Electricity generation of the CHP unit in MWh | 40,274 | 40,274 |
| Primary energy factor of electricity | 2.8 | 2.8 |
| Own electric consumption of the system in MWh | 1,291 | 1,291 |
| Primary energy factor of electricity | 2.8 | 2.8 |
| Purchased bio-heat in MWh | 0 | 22,800 |
| Primary energy factor of bio-heat | 0 | 0 |
| Total delivered heat energy in MWh | 177,509 | 177,509 |
| **Primary energy factor** | **0.97** | **0.80** |

The purchase of bio-district heat reduces the primary energy factor $f_{p,FW}$ of the energy center to a value of **0.80**.

**EnEV - example NPB**

The improvement of the primary energy factor of the energy center reduces the primary energy requirement for space heating $\mathbf{W_{p,heat}}$. This has a positive effect on the fulfillment of the EnEV. In case of the new production building, the value for the primary energy requirement with the new primary energy factor (0.80) can be calculated by the use of equation (9) (see equation (22)).

$$\boldsymbol{W_{p,total} = W_{p,el} + f_{p,FW} \cdot W_{del,heat} = 75.23\ \frac{kWh}{m^2a}} \qquad \textbf{(22)}$$

This result undercuts the limit for a reference building (87.37 kWh/m²a) according to DIN V 18599 (see 3.4 DIN V 18599) by 13.9 % (instead of 4.6 % with the actual value for $f_{p,FW}$). The compliance of the EnEV does not represent a serious obstacle for the NPB if the arranged amount of bio-district heat is purchased and inserted into the system. Consequently, and with high probability, this measure also ensures a secure fulfillment of the law for further construction projects.

**REHA - heat supply area**

The purchase of bio-district heat can be categorized as “District heat or cold” (replacement measure, see 3.3.2 Replacement measures) regarding the REHA, because the heat quality and production fulfill all criteria of the act. The acquired heat energy originates from gaseous biofuel, which is combusted in a CHP unit on a new technical state and therefore has to cover an obligatory share $OS_{Bio}$ of 30 % (see 3.3.1 Integration of renewable energies).

An annual bio-heat purchase of 7,600 MWh in a period of 3 years delivers a total amount of 22,800 MWh of “green” heat energy. For the same period an overall heat generation of 190.133 MWh (see Table 8) by the energy center is measured. The proportionate heat supply by bio-district heat therefore is 12.0 % which corresponds to its coverage ratio $CR_{Bio.}$ The achieved degree of fulfillment by this measure is consequently, according to equation (7), 40.0 %.

By the use of equation (8) the degree of fulfillment $DF_{SA}$ for all buildings within the supply area can be determined (see equation (23)). It origins exclusively from the energy center and consists of the contributions of the bio-district heat and the CHP unit ($DF_{CHP}$ = 43.5 %). Coverage ratios resulting from building- specific components or measures are not considered.

$$\boldsymbol{DF_{SA} = \sum_i \frac{CR_i}{OS_i} = DF_{Bio} + DF_{CHP} = 40.0\,\% + 43.5\,\% = 83.5\,\%} \qquad \textbf{(23)}$$

Consequently, in the whole supply area of the energy center only 16.5 % of the degree of fulfillment has to be covered building-specifically.

**REHA – example NPB**

In case of the new production building the annual primary energy requirement of the building is undercut by 13.9 % in consideration of the bio-district heat. The value for the minimal undercutting of the EnEV is therefore, on the base of the actual planning data, delivered by the opaque surfaces (8.6 %), what provides a degree of fulfillment for the REHA of $DF_{EnEV}$ = 57.3 % (see 5.3.1 Present situation). Furthermore, the heat recovery by the air exchange unit can be taken into account with a degree of fulfillment of $DF_{recovery}$ = 59.6 % (see 4.6.2 Renewable Energies Heating Act (REHA)). Adding the building-specific measures and the contribution of the heat production of the energy center, equation (8) delivers the following degree of fulfillment (see equation (24)):

$$\boldsymbol{DF_{total}} = \sum_{i} \frac{\boldsymbol{CR_i}}{\boldsymbol{OS_i}} = \boldsymbol{DF_{Bio}} + \boldsymbol{DF_{CHP}} + \boldsymbol{DF_{EnEV}} + \boldsymbol{DF_{recovery}} = \mathbf{200.4}\ \% \qquad \textbf{(24)}$$

The requirements of the Renewable Energies Heating Act are over achieved (200,4 %) in case of the purchase of the bio-district heat offered by the public utility company . The energy center with its composition already covers 83,5 % of the necessary heat amount for the supply area, so the building-specific contribution is very small. A positive excess of the ENEV on a small scale is sufficient to comply the act. The input of the heat recovery in the heat exchange unit is not even necessary under those conditions (of course still recommendable in the sense of sustainability). Figure 22 summarizes the calculation graphically.

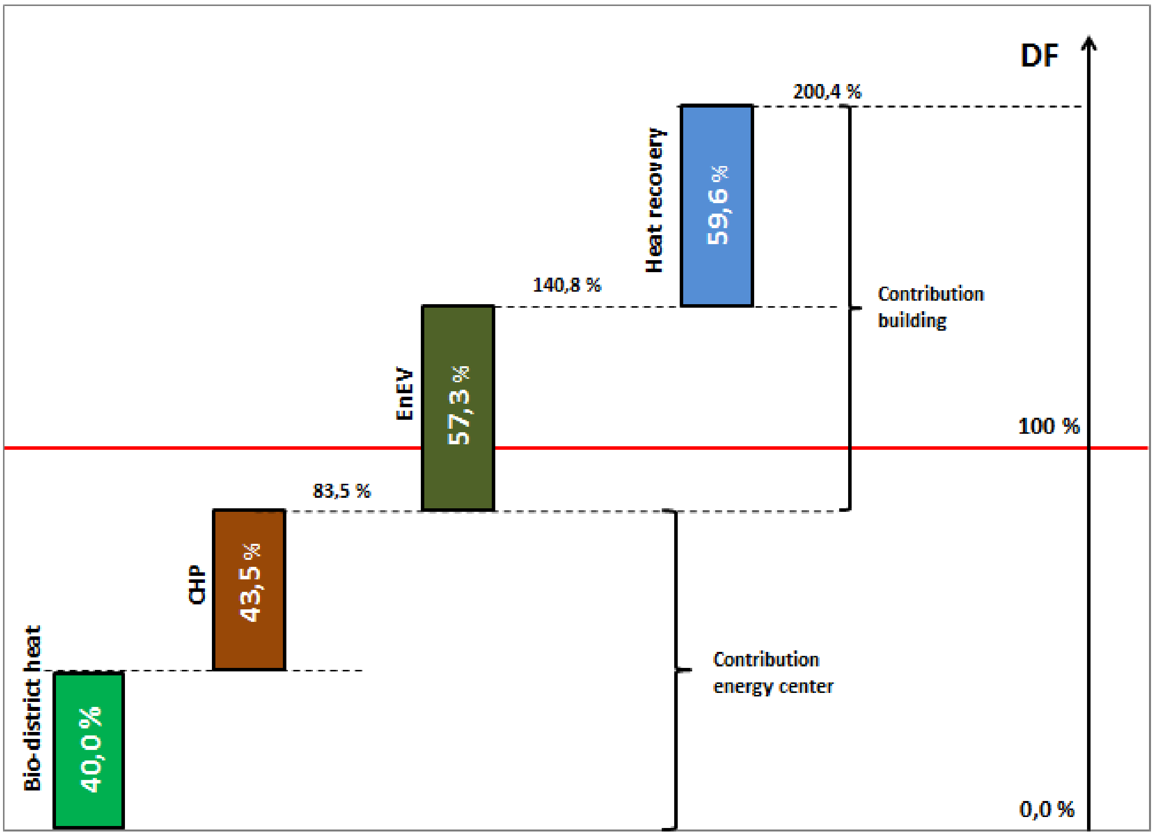


**Figure 22: Effects of the bio-district heat on the compliance of the REHA – example NPB, own design**

The results of the case study NPB demonstrate that the alternative „Purchase of bio-district heat" ensures (with a very high probability) the compliance of both laws on the energy efficiency of buildings for all construction projects in the supply area of the energy center . Even buildings, not equipped with an air exchange unit, can fulfill the criteria of the regulations with this measure.

**Summary**

The purchase of bio-district heat from the public utility company improves the situation regarding the energy efficiency laws for buildings for the supply area strongly. The fulfillment of the EnEV is facilitated by the reduction of the primary energy factor which contributes to the REHA. In addition, the bio-heat itself contributes by the proportionate heat energy produced by RE (see Figure 23). In case of the implementation of this alternative, problems to receive a building permit (because a violation of the energy laws for buildings) are very improbable for construction projects in the whole supply area.

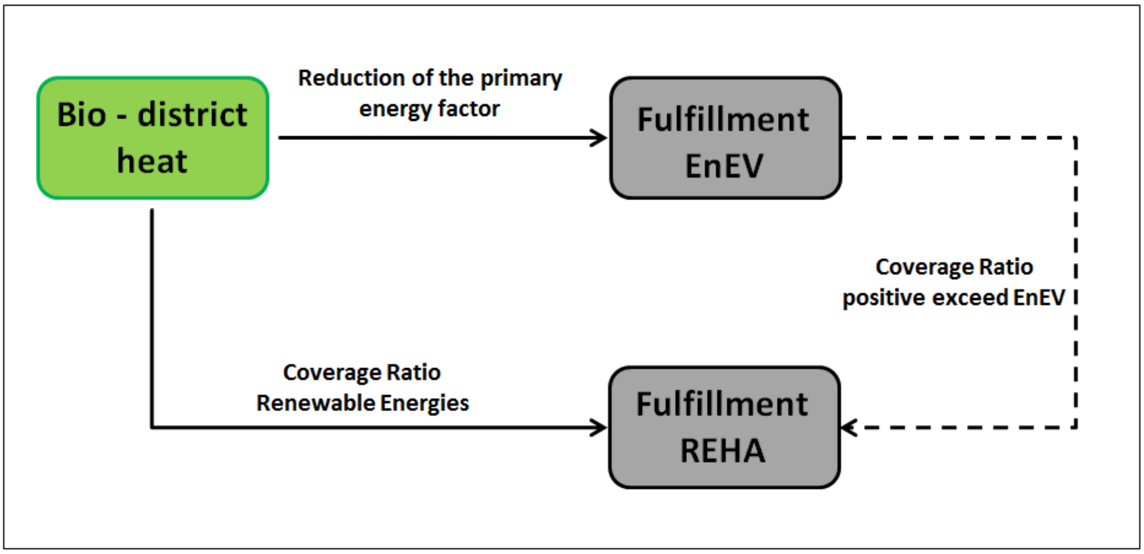


**Figure 23: Effects of the bio-district heat on the energy laws for buildings, own design**

### 6.2.3 Investment appraisal

The public utility company is offering the following commercial conditions[20] (project period = 15 years) to the company:

**Table 21: Composition of the compensations for bio-district heat, own design**

| Type of compensations | Amount in € |
|---|---|
| Building cost subsidy | 250,000 |
| Basic price per month | 42,020 |
| Work price per kWh heat | 0.05 |

Furthermore, the installation and connection of the local heat transfer station is the task of company. For that further costs for construction measures and adaption of the control automation of the heat supply system emerge:

[20] Data is descended from the E-Mail traffic with the public utility company

**Table 22: Cost estimate - connection to the district-heat grid of the public utility company, own design**

| Cost factor | Amount in € |
|---|---|
| Installation of the pipeline[21] | 245,000 |
| Breakthrough of the building envelope | 22,500 |
| Connection to the existing system | 65,600 |
| Building automation system | 57,100 |

In total fix investment costs $C_{fix}$ (building cost subsidy, construction measures and connection to the existing automation system) of 640,200 € arise through the implementation of the alternative "purchase of bio-district heat".

Every month, besides the basic price of the public utility company (42,020 €, see Table 21), additional costs $AC_{m,Gas}$ resulting from the difference of the work price of bio-heat and the price for heat generation by natural gas occur. The planned amount of heat transfer of $Q_{Bio,a}$ = 7,600 MWh with a price of 0.05 €/kWh produces additional monthly costs in contrast to combustion of natural gas[22] with a gas price[23] of 0.03211 €/kWh and an efficiency of the boilers of $\eta_{boilers,Hu}$ = 85.67 % (see Table 8, bio-heat replaces heat production from boilers as the CHP unit is always running at nominal power). They are calculated in equation (25).

$$\boldsymbol{AC_{m,Gas} = \frac{Q_{Bio,a}}{12} \cdot \left( Work\ price\ bio - \frac{Gas\ price}{\eta_{boilers,Hu}} \right) = 7,928.68\ €} \quad \textbf{(25)}$$

In conclusion, running monthly costs $C_{monthly}$ of 49.948,68 € (basic price and additional work costs $AC_{m,Gas}$) are produced by this alternative..

By the use of equation (2) the net present value of the measure can be determined. In case of the realization of the alternative bio-district heat fix investment costs $C_{fix}$ and monthly running costs $C_{monthly}$ occur with a project period $n_y$ of 15 years. The net present value can be determined in combination with the annuity method (see 2.6.2 Annuity) as the monthly running costs represent periodic cash-flows (annuities A) of the same amount of money. In the equation the fix investment costs as well as the monthly costs have to be balanced negatively. The nominal annual interest rate $i_{nom,an}$ used by the company company is 8 %[24]. The nominal annual interest rate can be transferred to a relative monthly

[21] The costs for the implementation of the pipeline are calculated by the construction department of the company
[22] The combustion of 0,6 % fuel oil is neglected in the determination of the additional costs
[23] Medium price for natural gas of the supplier in 2015
[24] Information of the internal financial department of the company

interest rate $i_{rel,m}$ of 0.67 % by the use of equation (4). The project period $n_y$ is 15 years which equals 180 monthly cash-flow periods $n_m$.

$$NPV_{Bio} = -C_{fix} - C_{monthly} \cdot \left[ \frac{(1 + i_{rel,m})^{n_m} - 1}{i_{rel,m} \cdot (1 + i_{rel,m})^{n_m}} \right] = -\,5{,}866.859 \quad € \qquad (26)$$

The net present value $NPV_{Bio}$, calculated in equation (26), of the project „Purchase of bio-district heat" is – 5,866,859 €[25]. Table 23 summarizes all the calculations.

**Table 23: NPV-bio-district heat, own design**

| Cost factor | Value | Unit |
|---|---|---|
| Construction measures, connection automation | - 390,200 | € |
| Building cost subsidy | - 250,000 | € |
| **Total fix investment** | **- 640,200** | **€** |
| Basic price per month | - 42,020 | €/month |
| Work price for bio-heat | 0.05 | €/kWh |
| Work price for natural gas - heat | 0.0321 | €/kWh |
| Additional costs for bio-heat | - 7,928 | €/month |
| **Running costs per month** | **- 49,948** | **€/month** |
| Nominal annual interest rate: | 8,00 | % |
| Relative monthly interest rate: | 0,67 | % |
| Product period in years | 15 | years |
| Product period in months | 180 | months |
| **NPV** | **- 5,866,859** | **€** |

## 6.3 Improvement of the insulation

In this subsection the alternative to improve the insulation of a building to effect the situation regarding the energy efficiency laws is discussed.

### 6.3.1 Framework conditions

By an improvement of the building insulation, heat losses through the surfaces of a building can be reduced. Especially in winter an adequate insulation can save high amounts of energy, whereas in summer a level of insulation can also lead to an increase of necessary cooling work, because of heat congestion. Causing contrary effects, this measure can only be implemented in a small scale to save energy.

[25] The correctness of the calculation is confirmed by the internal financial department of company

### 6.3.2 Effect on the energy laws

The Energy Savings Regulation (EnEV) contains maximum limit values for the insulation of new buildings. The heat transfer coefficient U of opaque surfaces is not allowed to exceed the value of 0.28 W/m²K (see 3.2.2 Limits for the heat transfer coefficients). To undercut this value is a binding condition for the replacement measure of positively exceeding the EnEV.

Savings of space heating energy due to a better insulation reduce the primary energy requirement, what positively influences the situation regarding the EnEV.

**EnEV - example NPB**

For the case study NPB EnEV-calculations are available for different values of U (heat transfer coefficient). The improvement of the insulation (decreasing the U-value) reduces the delivered energy use for space heating and by that also the primary energy consumption of the building. The planning value for U (opaque surfaces) is 0.256 W/m²K. The annual primary energy requirements are also calculated for a higher U-value of 0.271 W/m²K by the application of the software „Solar-Computer“. A reduction of the U-value by 0.015 W/m²K decreases the annual requirement of delivered energy for space heating by 1.47 kWh/m²a (respectively the primary energy requirement by 1.43 kWh/m²a). By that difference the EnEV can be undercut by 1.6 % more (see Table 24).

**Table 24: EnEV calculation – variation U-value, own design**[26]

| Verification EnEV 2014 with tightening 2016 ($f_{p,FW}$ = 0.97, all values in kWh/m²a) | | |
|---|---|---|
| **U-Value in W/m²K** | **0.256** | **0.271** |
| Delivered energy use for space heating | 43.52 | 44.99 |
| Delivered energy use for hot water | 4.03 | |
| Total delivered energy for heating $W_{del,heat}$ | 47.55 | 49.02 |
| Primary energy for heating $W_{p,heat}$ | 46.12 | 47.55 |
| Delivered energy – other consumers $W_{del,el}$ | 20.60 | 20.60 |
| Primary energy – other consumers $W_{p,el}$ | 37.19 | 37.19 |
| Total primary energy consumption $W_{p,ges}$ | **83.31** | **84.74** |
| Proportion of heating | 55.4% | 56.1% |
| Legal limit of the reference building for primary energy $W_{p,max}$ | **87.37** | |
| Proportional undercutting of the reference value | 4.6% | 3.0% |
| **Fulfillment EnEV 2014 with tightening 2016** | **yes** | **yes** |

[26] The calculations for this comparison are performed with the software „Solar - Computer“ (Modul B55, Version 5.13.01) and are restrained in the public version of the thesis

**REHA - example NPB**

The improvement of the building's insulation has positive effects on the EnEV. A positive excess of the latter can, as a replacement measure, contribute to the fulfillment of the REHA. To entirely comply that law by a positive excess of the EnEV the primary energy requirement has to be 82.08 kWh/m²a or lower (see 4.6.3 Significance of the results for further building projects). The value of the actual situation is 83.31 kWh/m²a. The difference between the actual and the necessary value is about 1.5 %. Previously, a stronger excess of the EnEV by 1.5 % ($OS_{EnEV}$ = 15 %) has been discussed. This would contribute a degree of fulfillment of 10 % to the REHA.

The U-Value of the opaque surface of the NPB has to be reduced by ΔU = -0,015 W/m²K (in average) to fulfill the REHA by this measure.

**Summary**

The improvement of the insulation is a building-specific measure to reduce the primary energy requirement of a building. This has a positive impact on the fulfillment of the EnEV. The latter can contribute by a positive excess to the compliance of the REHA (see Figure 24).

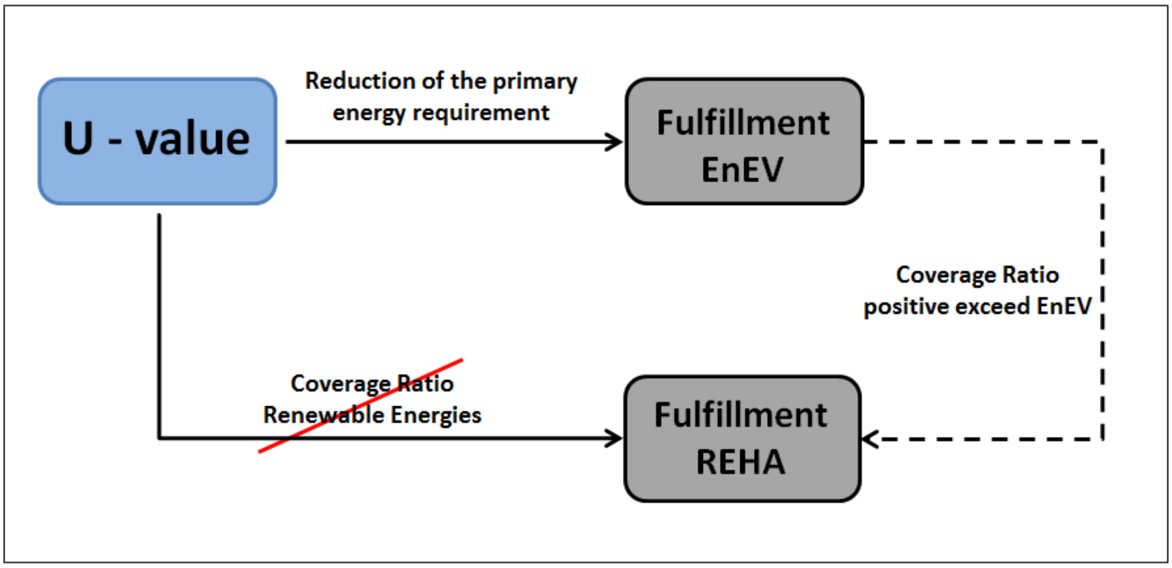


**Figure 24: Effects of the insulation improvement on the energy laws for buildings, own design**

Due to the contra effects of the reduction of heat losses and the consumption of energy by cooling (both results of a better insulation), this alternative can only be implemented in very small scales. Therefore, this measure possesses limited capacity to improve the legal situation.

### 6.3.3 Investment appraisal

The scale of the investment for the improvement of insulation is calculated based on the NPB as example. To fulfill the REHA a reduction of the heat transfer coefficient by ΔU = -0.015 W/m²K is necessary (see 6.3.2 Effect on the energy laws).

The total surface of the NPB building consists of 22,051 m² exterior wall, 16,050 m² roof surface and 2,594 m² window area. [27]

The specific prices for the improvement of insulation are available from internal information of the company.[28] A thickening of an exterior wall by 40 mm ($\Delta U$ = - 0.07) costs 25 €/m². For the roof surface the necessary amount of money for 40 mm of extra insulation ($\Delta U$ = - 0.04) is 10 €/m². The window area (transparent surface, 13.3 % undercut of the maximum of the EnEV) has already the highest standard (triple glazing) and has therefore not to be improved.

A necessary reduction of the heat transfer coefficient by $\Delta U$ = -0.015 W/m²K causes costs for the exterior wall of $C_{wall}$ = 5.36 €/m² and for the roof surface of $C_{roof}$ = 3.75 €/m². In consideration of the building's composition the following investment for additional insulation to fulfill the REHA is required (see Table 25):

**Table 25: Investment for additional insulation, own design**

| Surface | Area in m² | Specific costs in €/m² | Total costs in € |
|---|---|---|---|
| Exterior wall | 22,051 | 5.36 | 118,193 |
| Roof | 16,050 | 3.75 | 60,187 |
| | | | **178,380** |

The total costs emerge directly and not in future accounting periods, therefore this investment also represents the net present value NPV (- 178,380 €).

(Positive future cash-flows caused by the energy cost saving due to the improvement of insulation are very small and negligible.)

## 6.4 Confrontation of the options

### 6.4.1 Comparison

PV plants and the improvement of the insulation are building-specific measures, whereas the purchase of bio-district heat influences the whole supply area.

PV plants cannot be placed on every construction in the required scale (or at all, see 6.1.1 Framework conditions). The improvement of the insulation is only available for effects in a small scale (see 6.3.1 Framework conditions). The purchase of bio-district heat however, represents a long-term solution for the compliance of the energy efficiency laws on the performance of buildings for the whole supply

[27] The division of the building's surface is extracted from the calculations by the software „Solar – Computer“, the relevant part is restrained in this public version of the thesis
[28] The costs per area for the improvement of the insulation are descend from existing project information (latest construction project of the company)

area. The case study new production building (NPB) proofs, that this option ensures a significant positive excess (see 6.3.2 Effect on the energy laws) of both regulations (EnEV and REHA).

The investment for a PV plant (case study NPB, 442.340 €, see 6.1.3 Investment appraisal) and the purchase of bio-district heat (640,200 €, see 6.2.3 Investment appraisal) lie relatively close together, although the alternative bio-district heat delivers a solution for the whole supply area and not only one building. Therefore, this investment can be classified as smaller. The investment for the improvement of insulation is 178,380 € in case of the NBK (see 6.3.3 Investment appraisal).

Having investments in similar scales, the net present values of the options differ significantly. The PV plant possesses a NPV of about – 37,913 € (n = 15 years, see 6.1.3 Investment appraisal) due to positive cash-flows from own electric generation. The purchase of bio-heat does not cause any positive cash-flows during the project period of 15 years, on the contrary additional costs emerge (49,949 € per month) and lead to a NPV of about – 5.87 million € (see 6.2.3 Investment appraisal). The improvement of insulation generates no cash-flows besides the investment and therefore the absolute values of the investment and the NPV are similar (NPV = -178,380 €).

Table 26 summarizes the comparison of the different alternatives to improve the legal situation regarding the energy laws.

**Table 26: Comparison of the alternatives, own design**

| | PV plant | Purchase of bio-district heat | Improvement of insulation |
|---|---|---|---|
| **Availability** | depends on building structure | for the whole supply area of the energy center | for all buildings in a limited scale |
| **Affected units** | single building | heat supply area | single building |
| **Compliance of the energy laws** | securing of compliance if available in necessary scale | long-term securing of compliance | only applicable in case of a small-scale non-compliance |
| **Investment** | 442,335 € (case study NPB) | 620,200 € (heat supply area) | 178,380 € (case study NPB) |
| **NPV** | - 37,913 € (case study NPB) | - 5,866,859 € (heat supply area) | - 178,380 € (case study NPB) |

### 6.4.2 Evaluation

The most advisable and sustainable approach for the design of the future supply area of the energy center in the framework of the law is the purchase of bio-district heat. The alternatives PV and insulation do not provide a base for the compliance of energy laws for the whole future building stock and therefore problems in receiving construction permits can arise in certain building projects.

However, the net present values of the alternatives differ a lot. Whereas the PV plant generates positive cash-flows and has a payback-period of 18 years (see 6.1.3 Investment appraisal), the purchase of bio-heat produces costs of almost 6 million € over the project period. The NPV for the improvement of insulation is equal to the initial investment. From an economic point of view the alternative PV is the best solution.

For the concept of the future strategic energy supply the company has to weight up the risk of not receiving a construction permission for a specific building (due to the unfeasibility of a building-specific improvement measure) with the monetary losses by the possible implementation of the alternative bio-district heat.

# 7. Conclusion

Climate protection attracts more and more attention in the world public and action is necessary for sustaining the world's environment. To consciously use energy is one way to contribute to a positive development. As the energy supply of buildings covers a significant share of the overall energy use, the European Union releases directives on the energy performance of buildings, which are transposed into national law.

The objective of this thesis is the development of a sustainable concept for the strategic energy supply of the company site against the background of this type of laws.

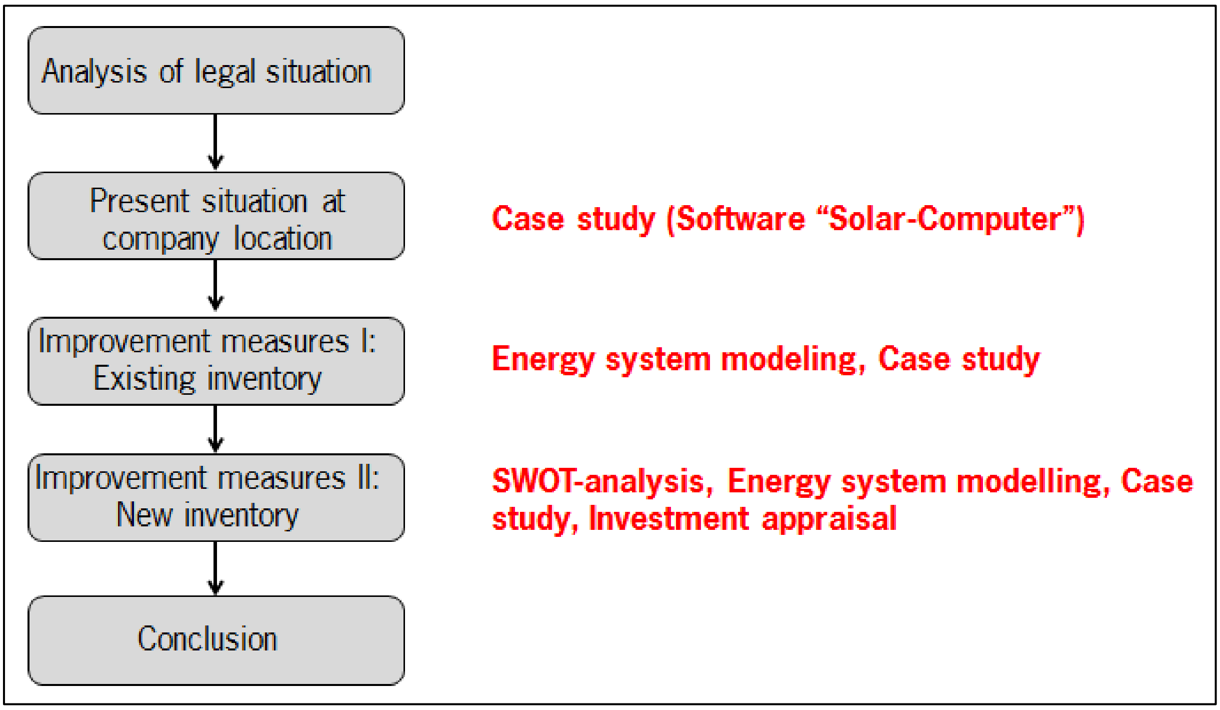


**Figure 25: Methodology (own design)**

Figure 25 summarizes the methodology performed in this thesis. To achieve the objective of the work, I first of all identified the legal situation regarding the energy performance of buildings and transferred the results to the conditions of the company site (external analysis - SWOT). For examining the present situation concerning this matter I performed a case study (new production building) by the application of the software "Solar-Computer" (internal analysis – SWOT). Afterwards, inventory neutral procedures are considered. As a consequence I determined the real primary energy factor of the heat supply system by the method of energy system modelling and obtained a positive result (0.97 instead of 1.10), which was certificated by an external and neutral institution  and is therefore useable in front of the court for legal procedures. To obtain all necessary data for the calculation was a very difficult process because I head to read out a lot of data from the building automation and estimate several energy requirements of components to achieve the energy consumption of specific parts of the system. To analyze the influence of the decrease of the primary energy factor on the legal situation I performed the case study with the software “Solar-Computer” again. Having explored the heat supply system and its framework conditions (internal analysis - SWOT) as well as further possible improvement measures (external analysis - SWOT) including their influence on the energy laws (case study), I came up with three strategies by the use of the SWOT-analysis. One of the strategies (purchase of bio-district heat) emerged during the process of the thesis. By following the recent events on the newspapers, the possible construction of a bio-waste treatment plant next to the company site offered new opportunities for the integration of RE to the heat supply. Negotiations with the partners were made and a possible strategy emerged. In the last step the strategies are evaluated on their effects on the legal situation (based on the case study and the energy system modelling) and an investment appraisal for all the options is done.

A further achievement of the thesis is the identification of the possibility to include waste heat of gadgets into the calculations for the compliance of the energy laws. In case of the new production building the waste heat of the welding robots enables the fulfillment of the Renewable Energies Heating Act without further measures (proofed by a service company).

After all considerations in the frame of this thesis, my conclusion and recommendation to the energy department of the company is, from an economic point of view, to install PV plants on a building if it cannot comply the energy laws. Nevertheless, due to the limits of feasibility of this option in certain cases, the risk of non-compliance should be assessed and weighted up with the option to ensure a long-term compliance by the more expensive connection to the bio-district heat grid. In addition, the investment appraisal is executed using static prices (recent market/supplier price) for gas and electricity. If, as an example, the natural gas price increases in the next years, the purchase of the bio-district heat generates less additional costs or can even produce positive future cash-flows. For a more precise analysis the prognosis of the future development of these prices should be included into the investment appraisal.

To sum up I recommend to the company to put further effort into the decision procedure by doing a risk assessment and an investment appraisal considering the future trend of energy prices.

Key words: Climate protection, energy performance of buildings, strategic energy supply, case study, energy system modelling, SWOT-analysis, investment appraisal, bio-district heat, risk assessment, future trend of energy prices

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# Appendix - Official Journal of the European Union



*ANNEX I*

**Harmonised efficiency reference values for separate production of electricity (referred to in Article 1)**

In the table below the harmonised efficiency reference values for separate production of electricity are based on net calorific value and standard ISO conditions (15 °C ambient temperature, 1,013 bar, 60 % relative humidity).

| | Year of construction: Type of fuel | 2001 and before | 2002 | 2003 | 2004 | 2005 | 2006-2011 | 2012-2015 |
|---|---|---|---|---|---|---|---|---|
| Solids | Hard coal/coke | 42,7 | 43,1 | 43,5 | 43,8 | 44,0 | 44,2 | 44,2 |
| | Lignite/lignite briquettes | 40,3 | 40,7 | 41,1 | 41,4 | 41,6 | 41,8 | 41,8 |
| | Peat/peat briquettes | 38,1 | 38,4 | 38,6 | 38,8 | 38,9 | 39,0 | 39,0 |
| | Wood fuels | 30,4 | 31,1 | 31,7 | 32,2 | 32,6 | 33,0 | 33,0 |
| | Agricultural biomass | 23,1 | 23,5 | 24,0 | 24,4 | 24,7 | 25,0 | 25,0 |
| | Biodegradable (municipal) waste | 23,1 | 23,5 | 24,0 | 24,4 | 24,7 | 25,0 | 25,0 |
| | Non-renewable (municipal and industrial) waste | 23,1 | 23,5 | 24,0 | 24,4 | 24,7 | 25,0 | 25,0 |
| | Oil shale | 38,9 | 38,9 | 38,9 | 38,9 | 38,9 | 39,0 | 39,0 |
| Liquids | Oil (gas oil + residual fuel oil), LPG | 42,7 | 43,1 | 43,5 | 43,8 | 44,0 | 44,2 | 44,2 |
| | Biofuels | 42,7 | 43,1 | 43,5 | 43,8 | 44,0 | 44,2 | 44,2 |
| | Biodegradable waste | 23,1 | 23,5 | 24,0 | 24,4 | 24,7 | 25,0 | 25,0 |
| | Non-renewable waste | 23,1 | 23,5 | 24,0 | 24,4 | 24,7 | 25,0 | 25,0 |
| Gaseous | Natural gas | 51,7 | 51,9 | 52,1 | 52,3 | 52,4 | 52,5 | 52,5 |
| | Refinery gas/hydrogen | 42,7 | 43,1 | 43,5 | 43,8 | 44,0 | 44,2 | 44,2 |
| | Biogas | 40,1 | 40,6 | 41,0 | 41,4 | 41,7 | 42,0 | 42,0 |
| | Coke oven gas, blast furnace gas, other waste gases, recovered waste heat | 35 | 35 | 35 | 35 | 35 | 35 | 35 |

ANNEX II

**Harmonised efficiency reference values for separate production of heat (referred to in Article 1)**

In the table below the harmonised efficiency reference values for separate production of heat are based on net calorific value and standard ISO conditions (15 °C ambient temperature, 1,013 bar, 60 % relative humidity).

| | Type of fuel | Steam/hot water | Direct use of exhaust gases (*) |
|---|---|---|---|
| Solids | Hard coal/coke | 88 | 80 |
| | Lignite/lignite briquettes | 86 | 78 |
| | Peat/peat briquettes | 86 | 78 |
| | Wood fuels | 86 | 78 |
| | Agricultural biomass | 80 | 72 |
| | Biodegradable (municipal) waste | 80 | 72 |
| | Non-renewable (municipal and industrial) waste | 80 | 72 |
| | Oil shale | 86 | 78 |
| Liquids | Oil (gas oil + residual fuel oil), LPG | 89 | 81 |
| | Bio-fuels | 89 | 81 |
| | Biodegradable waste | 80 | 72 |
| | Non-renewable waste | 80 | 72 |
| Gaseous | Natural gas | 90 | 82 |
| | Refinery gas/hydrogen | 89 | 81 |
| | Biogas | 70 | 62 |
| | Coke oven gas, blast furnace gas, other waste gases, recovered waste heat | 80 | 72 |

(*) Values for direct heat should be used if the temperature is 250 °C or higher.

*ANNEX III*

**Correction factors relating to the average climatic situation and method for establishing climate zones for the application of the harmonised efficiency reference values for separate production of electricity (referred to in Article 3(1))**

(a) Correction factors relating to the average climatic situation

Ambient temperature correction is based on the difference between the annual average temperature in a Member State and standard ISO conditions (15 °C).

The correction will be as follows:

(i) 0,1 %-point efficiency loss for every degree above 15 °C

(ii) 0,1 %-point efficiency gain for every degree under 15 °C

Example:

When the average annual temperature in a Member State is 10 °C, the reference value of a cogeneration unit in that Member State has to be increased with 0,5 %-points.

(b) Method for establishing climate zones

The borders of each climate zone will be constituted by isotherms (in full degrees Celsius) of the annual average ambient temperature which differ at least 4 °C. The temperature difference between the average annual ambient temperatures applied in adjacent climate zones will be at least 4 °C.

Example:

In a Member State the average annual ambient temperature in place A is 12 °C and in place B it is 6 °C. The difference is more than 5 °C. The Member State has now the option to introduce two climate zones separated by the isotherm of 9 °C, thus constituting one climate zone between the isotherms of 9 °C and 13 °C with an average annual ambient temperature of 11 °C and another climate zone between the isotherms of 5 °C and 9 °C with an average annual ambient temperature of 7 °C.

*ANNEX IV*

**Correction factors for avoided grid losses for the application of the harmonised efficiency reference values for separate production of electricity (referred to in Article 3(2))**

| Voltage | For electricity exported to the grid | For electricity consumed on-site |
|---|---|---|
| > 200 kV | 1 | 0,985 |
| 100-200 kV | 0,985 | 0,965 |
| 50-100 kV | 0,965 | 0,945 |
| 0,4-50 kV | 0,945 | 0,925 |
| < 0,4 kV | 0,925 | 0,860 |

Example:

A 100 $kW_{el}$ cogeneration unit with a reciprocating engine driven with natural gas generates electricity of 380 V. Of this electricity 85 % is used for own consumption and 15 % is fed into the grid. The plant was constructed in 1999. The annual ambient temperature is 15 °C (so no climatic correction is necessary).

In accordance with Article 2 of this Decision for cogeneration units older than 10 years of age the reference values of units of 10 years of age should be applied. According to Annex I to this Decision for a natural gas cogeneration unit built in 1999, which has not been retrofitted, the harmonised efficiency reference value applicable in 2011 is the reference value for 2001, 51,7 %. After the grid loss correction the resulting efficiency reference value for the separate production of electricity in this cogeneration unit would be (based on the weighted mean of the factors in this Annex):

Ref Eη = 51,7 % * (0,860 * 85 % + 0,925 * 15 %) = 45,0 %

## Statutory declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.