

Distribution of annual solar radiation within Germany (1)

## Energy efficiency potential of the European building stock: Case study for Germany

*Thesis for the degree in Mechanical Engineering*

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Department of Energy and Environment  
*Division of Energy Technology*  
CHALMERS UNIVERSITY OF TECHNOLOGY  
Göteborg, Sweden, 2013  
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### **Abstract**

In developed economies, such as the European Union's member states, the largest potential for energy efficiency improvements lies in retrofitting existing buildings. Thus, a model has been developed to assess the energy efficiency potentials for building stocks, the Energy, Carbon and Cost Assessment for Building Stocks (ECCABS). It simulates the energy flows in buildings and returns the emissions based on the energy demands. Germany in particular is interesting as it accounts for nearly 20% of all the population in the European Union, and thus also for a major share of its building stock. Thus, in a previous master thesis Wanjani and Bauer have already completed the characterisation of the Germany dwelling building stock. Now it is possible to simulate individual and aggregated measures and see their results in terms of energy and emissions. The model is completed by a cost analysis, as this is the most important factor for the house owners on deciding on any measure to take.

The simulations show that all investigated measures can be applied cost efficiently to parts of the building stock. The total savings per measure range from 1.24 TWh/a to 380 TWh/a for the whole building stock and 0.19 to 120 Mt CO<sub>2</sub>-equivalent respectively. The cost efficient savings rise up to 66 TWh/a which corresponds to 25 Mt CO<sub>2</sub>-equivalent. Further savings are achievable by subsidies, which go up to 150 bn. €/a and save up to 230 TWh/a and 632 Mt CO<sub>2</sub>-equivalent.

Keywords: German building stock, energy demand, energy saving measures (ESM), energy simulation, energy efficiency, cost analysis.

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## Table of abbreviations, acronyms and units

BMVS	<i>Bundesministerium für Verkehr, Bau und Stadtentwicklung</i> (Ministry for traffic, construction and urban development)
KfW	<i>Kreditanstalt für Wiederaufbau</i> (development bank)
U	heat transfer coefficient [ $\text{W}/\text{m}^2 \text{K}$ ]
WAvg.EAC	Weighted average energy costs [€/a]
WAvg.S	Weighted average savings [€/a]
WAvg.SNetE	Weighted average saved net energy [kWh/a]
WAvg.EmS	Weighted average saved emissions [t CO <sub>2</sub> -eq./a]
TotSDeLE	Total saved delivered energy [TWh/a]
TotEmS	Total saved emissions [Mt CO <sub>2</sub> -eq./a]
WAvg.CE	Weighted average energy costs [€/kWh*a]
WAvg.AC	Weighted average abatement costs [€/(tCO <sub>2</sub> -eq.*a)]
Cef TotSDeLE	Cost efficient total saved delivered energy [TWh/a]
Cef TotEmS	Cost efficient total saved emissions [Mt CO <sub>2</sub> -eq./a]
COP	Coefficient of performance [1]
SFD	Single family dwelling
MFD	Multi family dwelling
Bldg.	Building

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0	Baseline value /current value
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# 1 Introduction

Germany is with a population of about 82 million people the biggest country in the EU and correspondingly holds a major share of the buildings. Thus it is a major factor by achieving energy and emission saving goals in the housing sector.

The chapter will give a short introduction into the topic and introduce the *Pathway* project of which the thesis is part of. In addition the structure and the aim of the thesis will be presented. Concluded will the chapter be by general considerations and correlations related to the energy demand of buildings.

## 1.1 Background

In today's general discussion about energy, climate change and greenhouse gases the general public tends to simplify it to transportation and industry. But in Germany the private sector accounts for about one third of the German energy demand, as indicated in Figure 1. Even though much effort is taken, also by private persons, to increase the share of renewable energies, one may not forget that energy not consumed is the best energy saving measure.

The personal use of energy can be split up, among many other possibilities, into two categories. In the first category one can find all the consumption which is mainly based on personal habits, e.g. use of different methods of transportation. The other group sums up all the topics where no decisions on a daily base are made, e.g. type of fuel for heating, insulation of the house. The first group is mainly influenced and changed by attitude and psychology. Furthermore the general public moves to a greener life style, so a positive trajectory may be assumed. The second group is in a sense harder to change, as it in some cases includes major investments with very long lasting effects.

Building or renovation of a house is a demanding business, mentally and financially. But in this situation major decisions are to be made, which last for up to a century. 'How much money do I want to spend on insulation or an efficient heating system?' In the past, where low energy prices were assumed to be constant, houses were build rather less insulated and faster.

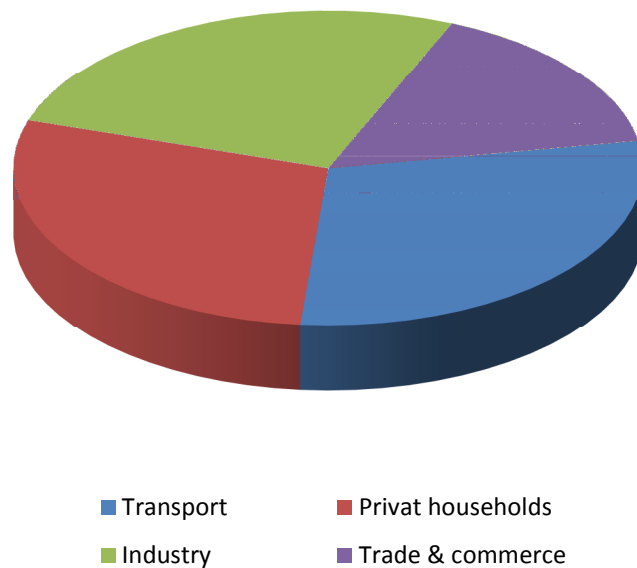


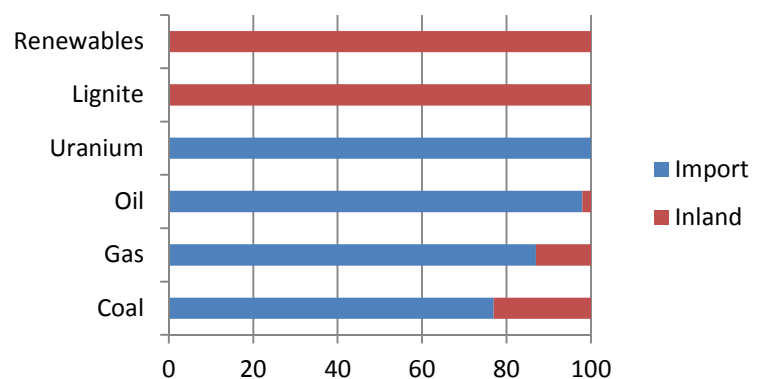
Figure 1: Share of energy demand in Germany by sector (2009) (Massen, 2012)

Besides all that personal issues also national and political issues have to be considered. Europe in general and especially Germany are relying on fuel imports. As a consequence money leaves the country (or continent) and is not spend locally. By reducing the costs for energy and increasing the share of value added in the local economy, also the national (or European) economy will benefit. This becomes clearer if one assumes that always the same share of salary is saved and the rest spend. So if there is less energy to pay for, there is more money to spend on the (local) economy.

**Table 1: Fuel supply Germany<sup>1</sup>**

Country	Gas and oil (position / share of import in %) (Berlin, o.a., 2012)	Coal (position / share of import in %) (Berlin, o.a., 2012)	Uranium (position) (Paaßen, 2010)
Algeria	8 / 2,5	---	---
Azerbaijan	9 / 2,5	---	---
Columbia	---	2 / 25	---
Kazakhstan	5 / 3,6	---	3
Libya	7 / 3,4	---	---
Niger	---	---	1
Nigeria	6 / 5,3	---	---
Russia	1 / 37,2	1 / 25	2
Uzbekistan	---	---	4

The political aspect is that it is much harder to convince someone, e.g. to more freedom of speech or human rights, if you are depending on its exports. Looking at the energy fuel exporting countries a certain coincidence may become obvious. This is actually a contradiction with



**Figure 2: Share of the different fuel used in Germany (import / inland)**

<sup>1</sup>the shares for uranium are hard to estimate, as the fuel is reused and resold

the energy strategic triangle (*'Energetisches Zieldreieck'*). The energy strategic triangle allows to rate energy sources according to 3 major aspects, security of supply, environmental impact and cost-effectiveness; where the first mentioned might be compromised rather easily.

A part of the security of supply is the duration, how long the fuel can be supplied. It is widely assumed that we already passed peak oil, the maximum oil banking capacity, and along with that declining oil resources. Also a simple change from one fossil fuel to another is not doing the trick, as peak (natural) gas and peak uranium will also come. Such changes in fuel might at most be seen to buy some time.

The last aspect, which is probably the most important one, is the 2°C climate target UNFCCC. As Germany is a big country, in terms of population and economy, also major saving potentials exist. As energy is a driving cost in the major companies, which account for the majority of the non-residential energy demand in Germany, they have applied measures to cut back on their consumption. Furthermore the emission trade scheme encourages the major energy consumer (and along with that greenhouse gas emitter) to reduce their impact on the environment. (Umweltbundesamt, 2013) The EN 1600 helps the industry, which uses a major amount of energy, to cut back in consumption and to optimise their production in terms of energy and emissions. Depending on the size of the energy used a whole team of engineers might be occupied. Thus a focus on the German housing stock seems more legit. All those problems are address in the 'Pathways to Sustainable European Energy Systems' project.

In addition small and medium-sized companies may also benefit from the measures proposed in this thesis and otherwise, as they often are based in a housed build for residential purpose. Especially the small businesses, and mainly the craftsmen among them, might benefit more from a specialised optimisation by their guild than from a rather general work like this.

Big companies, which account for the second third of the German energy demand, use individual energy optimisations; the suggestions made later can be seen as optimisation for the last third, private houses, and also small businesses.

As already stated by Vahlenkamp private houses have the biggest additional saving potential. Unlike onshore wind, which has a similar local added value and volume, the efficiency in the private houses has negative costs for reducing emissions. (Vahlenkamp, et al., 2012)

All the above stated arguments allow the reduction to the German dwelling stock.

## **1.2 Context of the thesis**

The thesis itself is part of the 'Pathways to Sustainable European Energy Systems', in the following abbreviated as Pathway (PW), a broad research project concerning all topics related to the future of energy in Europe. In this project several energy saving measures (ESMs) for dwellings have already been introduced and tested for the Swedish building stock. Those measures will now be introduced to the German building stock, if applicable. The impact of this introductions will be measured in costs, energy and emissions saved.

### **1.3 Aim of the thesis**

The aim of this thesis is to estimate the energy and cost saving potential in the German dwelling stock, with respect to several technical and non-technical restrictions and the resulting reduction in greenhouse gas emissions, in the following emissions. Based on this, suggestions of what actions to take will be given.

Besides the saving and efficiency measures directly related to everyday consumption also further measures are investigated. Those measures apply either to the planning phase or to the upstream chain e.g. building material. They are of special interest, as they consume the energy within a short time and are used for a long period of time. A good example of such is insulation material which is produced and used within weeks, but lasts for decades.

### **1.4 Structure of the report**

In a first step the data sources will be investigated, which were used for the simulations. This is the first and most critical step, as all further steps are based on that information gathered and fixed in the very beginning of the project. Along with the data, also currently in place (and finished) programs, policies and projects are presented.

The following chapter deals with the ECCABS model which will be presented in the first subchapter, followed by the updated values. Then follows a deeper look into efficiencies, as they are the major contributors to the success of any energy related project. These efficiencies also include the energy demand of building materials, as they also contribute to the total emissions of a building. The chapter will be concluded by introducing already broad up energy saving measures (ESM) during other work in the 'Pathways to Sustainable European Energy Systems' project and further suggestions. As the main aim is to reduce the emissions the change in fuels and the increase in efficiency are investigated on a more detailed level.

The results are presented in the following part of the report. The results will split up the usage of the different fuels used and the corresponding emissions will be presented. A comparison with similar work will be drawn to validate the results received.

The subsequent sensitivity analysis compensates for the uncertainty in predicting data and other values into the future.

The report then is concluded with a discussion, a conclusion and a suggestion for further work.

## 1.5 General considerations

As Germany decided to shut down all the nuclear power plants till 2020 and mainly new gas and coal power plants are in planning, the (average) emissions per kWh electricity will increase, assuming renewables will not be able to compensate. From this perspective, and that electricity has the highest exergy<sup>2</sup> of the considered energies, to reduce emissions electricity should only be considered the last option to choose.

To supply the same comfort to the inhabitants, which can be expressed as final energy, there are several ways to change/reduce the current system:

- 1) Increase efficiency  
By increasing the efficiency, less primary energy is needed to supply the same amount of final energy or comfort.
- 2) Substitute fossil fuels  
To reduce the emissions for the same final energy, less CO<sub>2</sub> intense fuels must be used, even though their (theoretical) primary energy demand might be higher. This can also be seen as an efficiency measure, as the emissions per final energy are reduced.
- 3) Decrease the demand  
The demand can be decreased either by decreasing the wasting, which is another form of efficiency or by changing habits, in this case of the inhabitants. This is mainly subject to psychological aspects which shall only be mentioned along the main argumentation, but not further investigated.

The expression of comfort as final energy can be shown by some simple examples, e.g. opening a can or drying laundry.

So, put in an easy expression, one could say: Demand and supply must be improved!

Along with increasing efficiencies and decreasing demands renewable energy sources need to be used, even if these result in a higher delivered energy demand. As they are renewable, this still decreases the emissions.

The report will group the type of fuel into two groups, fossil and renewable. The first group covers oil, gas, district heating, coal, electricity and others. Whereas the second group accounts for the rest, solar, biomass & waste, geothermal and other heat pumps. Whereas gas, district heating and electricity can be produced from renewable sources, they are mostly not. Thus the grouping is used in the following report. Even though the term renewable is not exactly right for solar, as the sun does not 'renew', but 'only' will exceed the lifetime of humanity, it follows the most common categorisation.

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<sup>2</sup> Exergy describes the ability to change one form of energy in another. The higher the exergy is the easier it is to change it into energies with lower exergies.

## 2 Standards and policies

In the following chapter the sources mainly used are introduced. These sources provide the data, which is the basis for the following simulations.

The second part introduces shortly the major regulations which refer to the building stock.

### 2.1 Data sources

As already mentioned above the data used are crucial and fundamental for the simulation, as they have a major influence on the outcome. The influence can also be seen in the sensitivity analysis.

To assure a sufficient precision of the numbers used, they were taken from official national and international statistics and cross checked if possible. Furthermore, earlier studies from universities and other recognised institutions have been included. A detailed list, of the studies referred to, can be found in the bibliography at the end of the report.

For the convenience of the reader the different sources are merged into two groups: official (national and international) and universities & other research facilities.

The group of official sources consists of the following:

- **Eurostat**

Eurostat is the statistical office of the European Union (based in Luxembourg) and provides data of all the member states and important neighbouring countries and trading partners.



- **DESTATIS: Statistisches Bundesamt (Federal statistics agency)**

The DESTATIS is the federal department for statistics in Germany and it is supplemented by the 16 state departments for statistics. They provide statistic data for Germany and its major trading partners and neighbours.



- **KfW: Kreditanstalt für Wiederaufbau (government-owned development bank)**

The KfW is a government owned bank in Germany which only purpose it is to provide money to the general public and industry in fields of special interest, e.g. education, local infrastructure or energy saving. All the government aid programs in that field are run by the KfW. The KfW also publishes all funding they have given and is therefore an excellent source for statistical data in the field of energy in the private dwelling sector.



- **UBA: Umweltbundesamt (Federal environment agency)**  
The UBA is part of the federal German ministry for environment, nature conservation and reactor safety. It funds and publishes research in different fields related to environment and is thus a valuable source for information, especially on the impact and potential of renewable energies.



- **EEA: European environment Agency**  
The European environment agency is one of the EU agencies and is run in cooperation with several neighbouring countries. The EEA provides as well the EU and other governmental boards, as well as the broad public with data concerning a broad variety of information related to environmental questions.



The second (academic) group consists of the following members:

- **IWU Institut Wohnen und Umwelt (Institute for living and environment)**

The IWU is a state funded (and owned) institute for research in the fields of

living, energy and integrated, sustainable development. It is also a major source for the prevent work by WANJANI and BAUER, on which this research is based.



- **ifeu - Institut für Energie- und Umweltforschung (Institute for research in the field of energy and environment)**

The IFEU is a private owned research facility (*GmbH*), which was a spin-off from the nearby University of Heidelberg. The institute looks back on over 30 years of independent research in the fields of energy and ecology and their economic consequences.



- **Schwäbsich Hall AG**

*Schwäbsich Hall* is a cooperative owned building society, which finances housing related project, like new buildings and (energy)

renovations. As one of the biggest building finances in Germany is a good source for actual average cost for certain measures.



## 2.2 Standards for dwellings

EU regulations apply to a various number of fields related to buildings. One of the major ones is the energy efficiency of appliances. This rates the different appliances on a scale<sup>3</sup> and gives the consumer the chance to choose an energy efficient product. This also allows further to ban products from certain classes from the market, e.g. light bulbs. This regulation is influencing this research, as electric appliances are treated as heat sources. As those regulations are already in place, only their influence (reduced heat gains from the electric appliances) will be investigated.

Along with those EU regulations also national regulations apply, which are mostly based on the EU regulations, but refer to the national institutions.

In Germany the federal founding is, as mentioned before, executed by the *KfW*. The *KfW* set standards whether a refurbishment is funded and/or subsidised or not and at which conditions. These standards vary with the laws concerning the energy use in dwellings. In addition the German laws from the late '70s to '90s have a similar character and must be included. The different regulations have different bases. While the laws refer to the net heating demand, the early *KfW*-standards use the primary energy demand as a reference. The newer standards, 2007 and later, also limit losses due to transmission.

The passive house standard and the *Effizienzhaus Plus* standard are not based on laws, but on architectural / civil engineering concepts. They both limit the primary energy demand and the *Effizienzhaus Plus* also the total energy demand. The fact that they use different bases for calculation makes them different from the standards mentioned above.

A detailed table can be found in appendix 9.1.

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<sup>3</sup> Scale going from A – F with A+, A++, etc. for different types of appliances.

### 3 Methodology

Whereas the last chapters introduced the context and the data used in this research, the following chapter deals with the methods and models used. The chapter is starting with the introduction of the core model and the updating of different characteristics of the German building stock. It then focusses on the efficiencies of different parts of the model. Following the investigated measures are introduced shortly and also the way of investing their financial and environmental impact is described.

#### 3.1 The Energy, Carbon and Cost Assessment for Building Stocks (ECCABS) model

The energy demand of a building is defined by its balance of the different energies, so influx minus outflow. An overview of the major heat gains and flows is given in Figure 3.

To estimate the heat and energy fluxes through the boundaries of a building basic heat and mass transfer is used. The ECCABS model uses two boundaries. All renewable and fossil fuels need to be converted into useful energy in the furnace. So the furnace is

treated as an independent system, which has the (fossil and renewable) fuels, for which the owner is charged for, as an influx and the heat gains and waste heat as outflows. Together with the other influxes and outflows they form the net energy balance of the system (building). In contrast the sum of all solar, fossil and renewable fuels is called delivered energy.

The simulation consists of two parts using two different programs, MATLAB and Simulink to calculate those balances. While Simulink is used to solve the energy balance of each building type, MATLAB handles the in- and output of the simulation. Additionally the emissions and costs of fuels are calculated, based on an input file. As the simulation is a projection in the future certain uncertainties occur, e.g. energy prices. These uncertainties can be used as an advantage by manipulating several values, e.g. taxes on emissions, to see the influence of the different parameters.

The output of the model is a file, which list the different energies:

1. Heat use: Space heating and hot water<sup>4</sup>

<sup>4</sup> Cooling is also possible, but it is neglected for Germany, as there are only a neglectable number of housings that are featured with air conditioning systems. (~0.5 %)

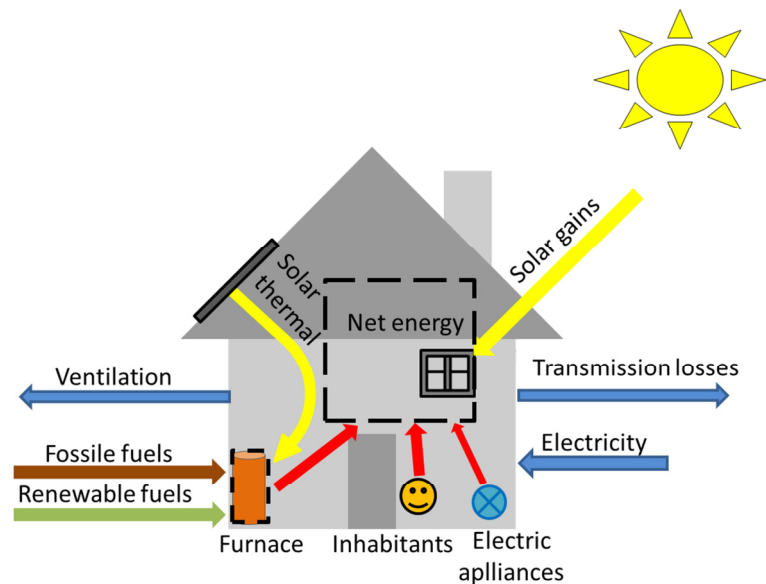


Figure 3: Energy flows of buildings

2. Heat gains: radiation, lighting, electrical applications, occupants
3. Heat losses and free cooling
4. Heat recovery: transmission, air conditioning systems
5. Electricity consumption: fans and hydronic pumps

The total energy demand can then be calculated by summing up 1 – 3 and 5 and subtracting 4. Furthermore, the demand for the different fuels and energies is presented, along with the costs and emissions associated to them. (Mata, et al., 2011)

### 3.2 Updating the data of the German building stock

To get an as accurate result as possible the data used for the simulation, especially the shares of the different fuels and the houses have to be as new as possible. As the data provided by Wanjani and Bauer are from December 2012, so just several weeks old, no major differing information where found. And thus, except for the introduction of heat pumps, no major changes were made.

The used values where compared with other data available, e.g. (Diefenbach, et al., 2011). Those values show similar magnitudes for the different types, but different shares in used fuels. This is reasonable, as those data is extracted from subsidies for renewing of furnaces. So the high shares of coal and electric heating are plausible, as they are much older and much more likely subject to change. Also the higher share of oil furnaces than of gas fuelled is plausible, as gas furnaces are more efficient and come with some other benefits and thus are preferred nowadays by the general public over oil furnaces within the last years.

Additional data for the heat pump is available for the different types of heat pumps and their average COP, but not for the type of building they are installed in. The following data was extracted and introduced:

**Table 2: Share and COP of heat pumps in the German buildingstock (Platt, et al., 2010)**

Heat pump	Type	Number	Share [%]	COP
A	Air-water	88,000	0.49	3.4
B	Brine-water	155,000	0.86	4.5
C	Water-water	26,000	0.14	4.9

As the share is rather small and the COP is depending on the temperature differences available in the specific application, an average COP was introduced on the base of the different COPs stated above and the shares they represent ( $COP_{av} = 4.179$ ). (Platt, et al., 2010)

Also the share of solar space heating and solar hot water production was introduced to 0.53% of the total production each. (Wasserstoff-Forschung, 2011)

More detailed information on the technique can be found in chapter 3.4.2.

To balance the energy the other fuels were decreased to fit a 100% ( $\pm 1\%$ ) heat supply to the building class.

As mentioned earlier Germany is going through a change in its electricity supply and thus the emissions per (average) kWh electricity will change. To be consistent all emission data used was taken from the GEMIS project. This data also includes the upstream chain for the different fuels. The data used can be found in the 9 Appendixes appendix. ((IINAS))

### 3.3 Construction and efficiencies

Reducing the energy consumption does not necessarily also result in a reduction of greenhouse gases. For this reason the overall emissions of different insulation types are compared shortly. Also the efficiencies of different energy converters will be investigated, which also play a major role in the delivered energy demand.

These efficiencies can be split up into two groups, due to construction or appliances. The construction ones are due to the civil engineering design of the building and mostly harder to change. The efficiencies to appliances are, in general, easier to change, but also much more depending on changing everyday habits.

#### 3.3.1 Construction

The construction efficiencies are dominated by the (outer) envelope. The envelope mainly consists, in terms of energy, of four different elements:

- Facade / (outer) walls
- Windows (and doors)
- Roof / attic (ceiling of the highest heated room)
- Basement (floor of lowest heated room)

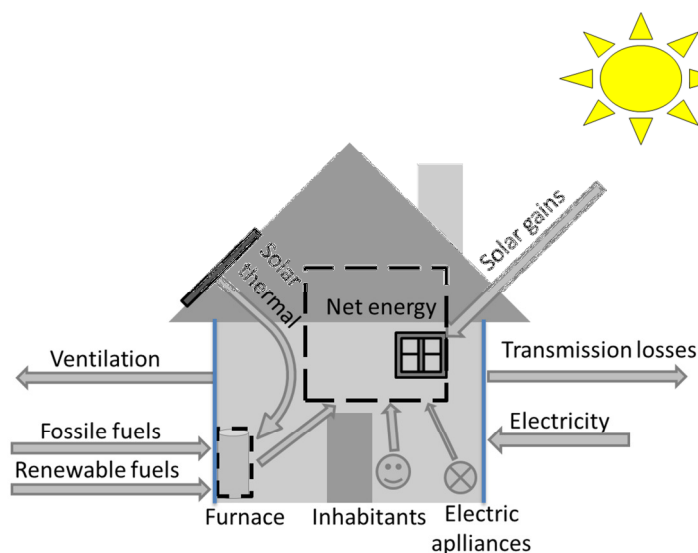


Figure 4: Insulation of walls

The facades are in today's discussion the main topic if it comes to energy efficiency in (private) buildings. On the one hand this is reasonable, as the outer walls contribute the majority of the envelope. On the other hand their heat transfer value is (already) rather low, compared to the one of windows. In addition strengthening of the envelope is generally considered a rather expensive and time consuming method. But nevertheless it is crucial, especially for older dwellings built before the first laws concerning energy

efficiency in November 1977. As it is seen by a lot of inhabitants as a major disturbance an

energy makeover of the outer envelope might be combined with aesthetic improvements, e.g. new painting. By this one could also make use of several synergies, e.g. only one scaffold needs to be erected.

The insulation increases the thermal resistance of the building against the environment. It attempts to keep the inside of the building at a constant and comfortable temperature. Never the less how big and good the insulation is, it will never be able to block all heat being transferred from the inside out (or the other way around). But this is not totally necessary, as minor air circulation increases the quality of the air, e.g. in terms of oxygen level or unpleasant odour. Furthermore the insulation, including the facades, also has the ability to store and supply heat over a longer time<sup>5</sup>. The same applies for 'cooling' in summer, when the insulation is not only a resistance to the heat flowing into the building, but also stores heat from the outside and thus keeps the inner of the building cooler. The facades can then purge the heat stored during the night or cooler times of the day.

The ECCABS model itself only accounts for the heat transfer coefficient, but not in which way it is achieved in the actual building. This is absolutely sufficient, as the heat demand is only depending on that. But as mentioned above, the insulation (including the facades) has a huge influence on the comfort inside a building. One can experience that by being in an old house (some centuries ago built) where at a hot day a pleasant climate can be found, whereas a building of newer construction dates, assuming the very same conditions, needs some kind of air conditioning to maintain the same comfort. This little example shows the influence of the heat capacity of the facades insulation system.

Another aspect is the energy balance of such insulation, because there is no point in investing more energy in transport, production etc., than it is saved later. If it comes to insulation material, two materials come in mind, as they are used widely: mineral wool and polystyrene panels. Besides those two there is a variety of different other materials and systems available. Besides the energy consumption of the different materials, also their availability is important. Availability in this sense means if the basic material is renewable or fossil, where renewable also includes otherwise waste materials from other processes. A detailed list can be found in the appendix.

The choice of the preferable material should also be depending on the local availability to reduce transport emissions, similar to the choice of roof covering before the introduction of standardised roof tiles. A good example of such are thatched roofs in Northern Germany. As the insulation will be not removed it may also be of interest how to recycle the materials. From that perspective two attributes would be perfect: reusable and easy to split in its basic compounds. All the renewable materials have the advantage that they are decomposable. This might be seen as the optimal solution, from today's point of view, as most of the left overs of a building are landfilled.

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<sup>5</sup> Assuming the insulation is applied outside.

The earlier mentioned example shows another alternative to extra insulation, thicker walls. Due to low energy prices in the past and faster constructing processes, demanded by the customers, the walls became thinner and thinner and less thermal resistant materials have been used. Now this time saving during the construction must be paid back with both higher energy demands (and costs) or an additional construction period. Thicker walling does not only apply to the new build dwellings, but also to the existing building stock. This insulation has several requirements, e.g. sufficient space, if the additional wall is to be erected inside. This might be necessary because of heritage status of the storefront or insufficient space in the direct area.

From table 9.3 in the appendix one can see that no matter which material will be used for insulation (e.g. to a standard of  $U = 0.2 \text{ W/m}^2\cdot\text{K}$ ) the primary energy will pay back within only some month or years at most. Also in terms of thickness all the materials result in a corridor between 20 and 30 cm, except for PU, wool slab and calcium silicate.

A much bigger effort needs to be taken by improving the thermal resistance of the windows (and doors, see Figure 5). As the windows can hardly be exchanged within a day, the inhabitants have to face major drawbacks in their comfort. In addition an exchange can only be done at good weather, no or just a little rain, and not to cold temperatures, as those would cause too much discomfort for the inhabitants.

The highest roof or insulating ceiling is the ceiling/wall which separates the heated area

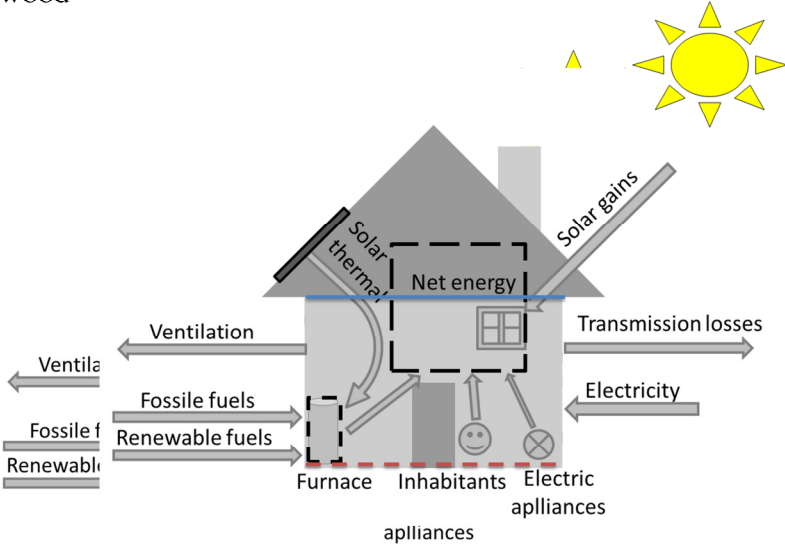


Figure 5: Insulation of windows and doors

of the dwelling from the unheated area above, see Figure 6. In most cases this is the ceiling of the top room. The basic method of insulation is rather simple, as mostly mineral wool is used. Today we see an increasing share of renewable, biomass based materials.

Much less effort needs to be taken to improve the insulation of the lowest floor. This is due to the fact that most houses have an unheated basement and the requirements in terms of tightness and (weather) durability are much lower (see Figure 6).

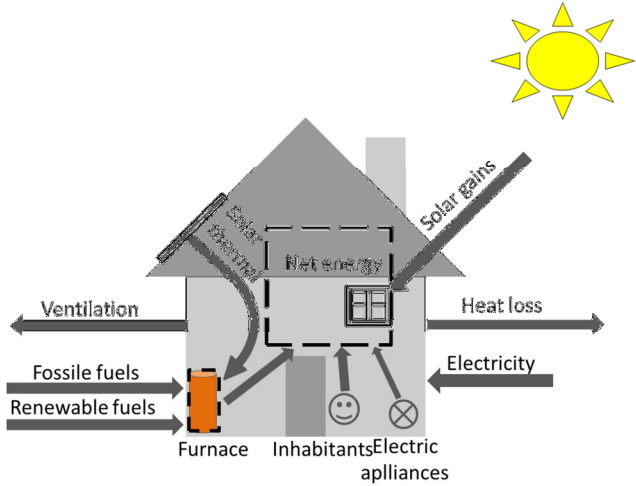


Figure 6: Insulation roof / highest ceiling (full) and lowest floor (dashes)

Another aspect is the so called a/v ratio. This characteristic of building is the ratio of the outer surface area and the volume enclosed. This ratio is very interesting from an energy point of view, as heat needs area to be transferred. So the more volume per dwelling, hence more people, are covered by the same outer surface, the less heat is transferred. This assumes the same temperatures and heat transfer rates. This is a planning aspect of a house, which can not be changed after the construction. As this aspect only applies to new dwellings it will not be further investigated in the discussion.

### 3.3.2 Furnaces

Furnaces, in this case, are all appliances, which aim it is to convert delivered energy<sup>6</sup> or electricity into heat or in a more general net<sup>7</sup> energy, see Figure 7. This unit varies a lot within the German building stock, whereas gas and oil boilers are most common and electrical furnaces are in the down. Also an increasing share of renewables can be found.

A study shows that in Germany about 88% of all used furnaces are not up to date. (Discher,

2010). Another crucial aspect,

concerning the heating device, is the right dimensioning. Like all other appliances also heaters have an optimal operation condition. The further away from such point a heater is operated the lower is the actual efficiency. This dimensioning is very much depending on the size of the dwelling, the climate and its inhabitants need for heat. This load varies during the year and along with that the efficiency of the heater. The more units are heated with one heating system the more average the heat demand will be, always considering the naturally given temperature changes over the year. From this one can see that heating systems covering one floor, or even less, are not very effective. Those systems can be found in rather simple multi-storey dwellings.

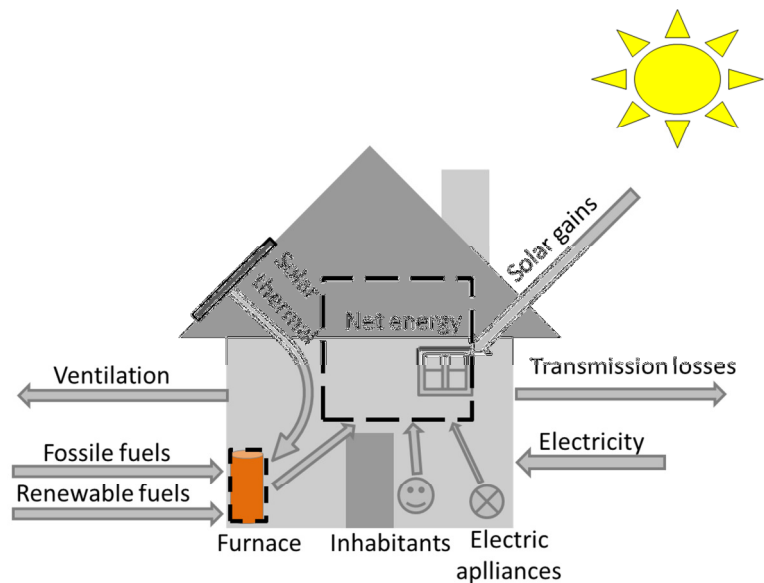


Figure 7: Furnace in the buildings energy system

<sup>6</sup> Delivered energy is sometimes also referred to as secondary energy.

<sup>7</sup> Net energy is sometimes also named tertiary energy.

Figure 8 below shows the degree of utilisation of different boiler types. This shows how much heat is gained per energy delivered as fuel, upper heating value.

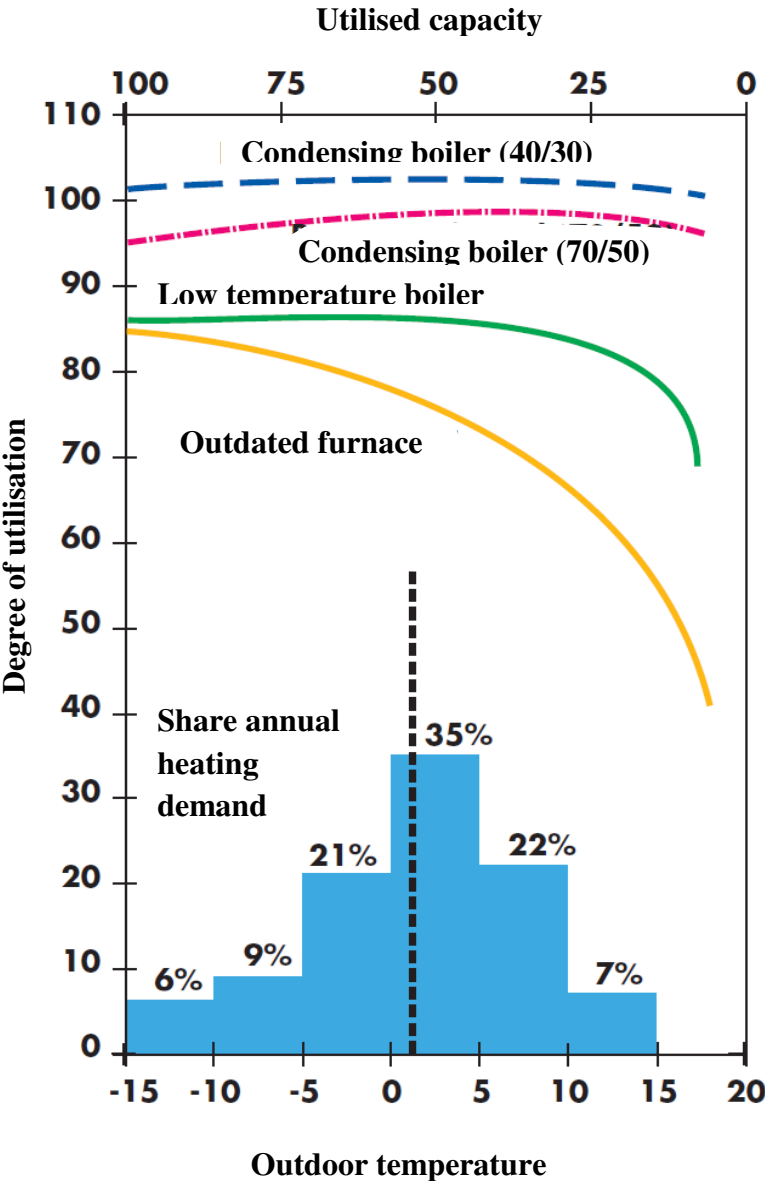


Figure 8: Characteristics of different furnaces

From Figure 8 the current average furnace efficiency can be estimated to about 90%. An update of the furnaces to condensate boilers can increase that efficiency to 96%. The numbers in Figure 8 refer to the lower heating value, which are thus about 5 % lower than the efficiency (referring to the upper heating value), which is used in this thesis. These values correspond to the values found in up to date furnaces, e.g. BUDERUS.

Another crucial part of the heating system is the circulation pump, which circulates the water from the furnace to the radiator and back. While old models run constantly new models run only when needed and at lower energy demand per heated floor area.

A further benefit which comes along with every change of a furnace is the readjustment to the actual heating demand. As stated above about 88% of all furnaces in Germany are out dated. As a result of rather cheap energy prices in the past, furnaces were over dimensioned. This wastes a lot of energy, specially keeping in mind that old furnaces have only in peak loads good efficiencies, but in lower loads the efficiency declines rapidly, as indicated in Figure 8. The dimensioning is also very much depending on the number of inhabitants, which may change over time. Also a simple readjustment of the heating program and regular maintenance increase the efficiency. (NRW) All those characteristics are far too much depending on the specific case and may thus not be further investigated in this research. But rather they may be seen as an additional benefit.

### 3.3.3 Appliances

Appliances are all further electrically powered units, except for heat pumps, which do not have the purpose of heating, see Figure 9. Appliances might be in this case split up into two different groups. The first group are all kind of (electric) lighting. The second group includes all the other machines used in (private) dwellings, e.g. oven, TV, stereo.

Other heat supplying units, as stoves, water boilers etc., should also be considered, as they are

mostly used on a daily basis and for a rather long time. Cooking is the second major energy consumer in buildings. In Germany mostly electric fire place can be found after a change over in 80's. In general there are three types of stoves commercially available. As mentioned above the most common one is the electric oven. This converts all the electric energy supplied into heat. Where this heat is transferred then is very much depending on the size of the bottom of the pot or pan used. This needs to fit perfectly to use all the heat and be of matching type. The second type is gas ovens, they can be found in older and commercial kitchens, as they come with certain benefits for cooking. In Germany gas ovens have a rather bad image as they are seen as old fashioned and dangerous (leakage of gas). Depending on the fitting of the pot or pan nearly all the energy is transferred from the gas to the food. The third and last is the induction oven. This converts also all the electric energy supplied into heat. As it requires special pots and pans they fit perfectly and nearly 100% of the heat is transferred.

The major difference, in terms of energy, is the source of energy. As the German electricity generation system has an average efficiency of about 33% this needs to be considered in the energy balance. Assuming for all three types same negligible losses for transportation and maintenance, the gas stove provides the highest efficiency.

Another often discussed aspect is the lighting. The EU commission adopted two regulations concerning the efficiency of lighting in 2009. Till 2012 all types of conventional filament lamp were banned from selling in the EU. The expected outcome of this is a reduction of about 15 million tonnes of CO<sub>2</sub> emissions. (EC45/2009, 2009) A further often neglected aspect is the transportation, production and recycling of the bulbs. Even though the new bulbs maybe a little more difficult to handle, the reduction of emissions and energy in transport (and other parts of the life cycle) are most favourable, as their lifetime is, even for the ones of poorest lifetime, more than six times higher. The best ones achieves up to 19 times the lifetime of a conventional bulb. This means saving 18 times the transport with trucks. The

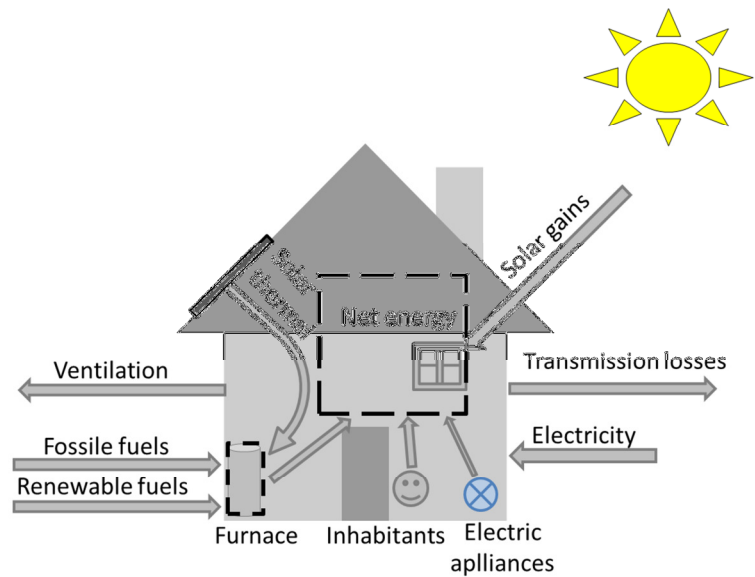


Figure 9: Appliances in the building energy system

annual energy demand is 88 kWh compared to 480 kWh for conventional bulbs. (Salzburg, 2013)

While dryers provide a certain comfort for the users, they also consume a lot of energy. The producers give values between 2 and 4 kWh per load (dena). The 42% efficiency of the average German power plant (Bundesumweltamt, 2013) more than doubles those values. Those values are for the up to date models, but not for the thousands of machines in current use, purchased 15 or more years ago using 30 kWh or more.

Clothes lines in contrast consume no electric energy at all during operation, but require more time and space. In addition the maintenance, production and recycling of dryers needs to be taken into account as well.

The use of dryers (in private households) is not only due to the personal comfort of the user, but also due to space available. So this issue should be kept in mind by the design of new dwellings.

The other mentioned appliances are subject to the European Union energy label. This label was introduced in directive 92/75/EEC and updated with directive 2010/30/EU. The label informs the consumer about the energy demand of the product. The rating is based on an average reference model or a fixed value (based on the category) and thus up to date. Nevertheless the differentiation in the high efficiency is rather poor, as all products above certain efficiency are grouped together whether they use 30% or 5% of an average model. A new, more detailed scale seems necessary.

In terms of energy all (electric) appliances can be represented by an energy or heat source in the model used in this thesis. This might suggest that there is no real need to improve anything from a bigger point of view. But one needs to keep in mind that all the electrical appliances use electricity, which is produced at about 42% efficiency in Germany.

The aim of the EU 20-20-20 project and this thesis is to reduce the CO<sub>2</sub> emissions, which are most often coupled to the energy demand, but not always. Also a change to climate neutral fuels, e.g. wood, or more efficient supply/production of tertiary energy also reduce the GHG emissions.

It can be summarised that all fuels need to be used as close to the area of production and the consumers to reduce emissions based on transportation. As the availability of sustainable, renewable fuels vary between the different regions within Germany, also the tertiary energy production as to be adjusted. Furthermore the political borders (at least within the EU) should be overstepped, to provide an optimal supply.

Special attention needs to be brought to residential accommodations, retirement homes and such. Those institutions have a mainly social goal rather than an economic. This suggests that there is some saving potential left. Even though only about 5% of all Germans live in such an accommodation, the potential might not be neglected. This is mainly due to the ownership, as it is owned not by a private person, but a legal entity. Such entities are mainly interested in a higher profit (whether it keeps the profit or not). Also long term investments are more likely,

as they can be seen as financial investments, without the drawbacks<sup>8</sup> of such investment in their own dwellings. (Jochum, et al., 2012)

These types of dwellings are also very interesting as they mostly come with in the rent included water, heat and electricity. This might reduce the effort to save on services which are already included in the rent. Rather simple methods, as motion detectors instead of switches, water efficient taps, toilets and showers will increase the efficiency of such dwellings.

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<sup>8</sup> These drawbacks are mostly due to the reduced comfort during the construction period.

### 3.4 Energy saving measures (ESM)

After establishing the model and creating a baseline, the current demand and the influence of different measures is tested. The measures can be grouped into three groups. The first one consists of the measures already mentioned in the pathway project. The second group investigates the changes in fuels and the inclusion of alternative energy sources. And the last group sums up all which are not mentioned by then. For all three groups a short list is given in the beginning and then a more detailed description of the different measures is presented. Depending on the measure, either a single simulation is done, or a sensitivity analysis.

The approach follows the idea of first to reduce the demand and then reduce the emissions (per kWh).

#### 3.4.1 Already in the Pathway Project mentioned measures

For single- and multi-family dwellings a list of measures has been published, with respect to the Swedish housing stock. This list is investigated first, as Germany has partly some common aspects with Sweden, like climate and building style.

The list is sorted by the energy saving potential of every measure (for Sweden):

**Table 3: Suggested energy saving measures for the Swedish building stock**

No	Measure
PW1	Use of thermostats to reduce indoor air temperature to 20°C
PW2	Ventilation with heat recovery (SFD)
PW3	Ventilation with heat recovery (MFD)
PW4	Increase of insulation of the facades
PW5	Increase of insulation of windows
PW6	Increase of insulation of cellar/basement
PW7	Increase of insulation of attics/roofs
PW8	Reduction of power used for the production of hot water to 0.8 W/m <sup>2</sup>
PW9	Reduction of power used for the production of hot water to 1 W/m <sup>2</sup>
PW10	50% power reduction of appliances
PW11	Reduction of power demand of circulation pumps
PW12	50% power reduction of lighting
PWA	Combination of all above

The German building stock differs from the Swedish one, specially keeping in mind the programs run in Germany within the last years to increase the share of renewable energies used and strengthen the insulation. Nevertheless it is a reasonable start as a rather large number of buildings might still be in their original (-energy-) setup.

The heat transferred through the wall (by conduction and convection) is direct proportional to the temperature difference and the U value of the wall. As the outer temperature is fixed only the **inner temperature** can be changed. This can be done by thermostats, which control the indoor temperature automatically, and thus reduce the heat transfer through the envelope.

**Model representation: Reduced  $T_{\min}$**

**Ventilation systems** exchange the air inside a building to guarantee a pleasant climate inside. The air going out is warmer as the air flowing in and the inflowing air must be heated to the inside temperature. The energy required for this could partly be gained from the outgoing air. As only 0.5% of all dwellings in Germany have an air conditioning system this method must be seen as a new investment, rather than a technical upgrade of an existing system.

**Model representation:  $H_{\text{Rec\_eff}} = 0.5$**

The **insulation** has a major influence on the heat demand of a building, as mentioned before. By increasing the thermal resistance less heat is transferred out of the building. The envelope consists, as mentioned above of several components with specific thermal resistances and shares in area. Special attention should be brought to heat bridges, which bridge the surrounding insulation of the (outer) envelope.

The (outer) envelope of a building consists of four main parts (from an energy perspective): (Outer) walls, windows, roof / attic and basement / lowest floor. The heat transfer is, as already mentioned depending on the U value of the envelope. This average U value can be decreased, so less heat is transferred, continuously. This means not all building from a certain class are insulated better, only the overall average. This allows to pick the buildings most promising, or best suiting by other aspects. Thus measures four to seven will be investigated as a sensitivity analysis.

**Model representation: Reduced overall U value**

The reduction of energy needed to **produce hot water** can be mainly achieved by using a more efficient (newer) boiler. Instead of reducing the (primary) energy demand to produce hot water, also the demand for hot water can be reduced by using inlets for taps, showers, etc. This saving potential is estimated to about 10%. (Kirchner, et al., 2009) Both reductions have the same representation in the model.

**Model representation: Reduced  $H_w$**

The **electric appliances** in a building work as a (electric) heater, as they transform a part of their electricity consumption direct into heat and the rest indirectly, with another step in between. This may be good in the first attempt, as it does not matter, for the temperature of the building, where the heat comes from. But as they are powered by electricity, the most exogetic energy available in private households (with a poor efficiency over the whole process) it becomes obvious, why the input of electricity should be reduced as much as possible.

**Model representation:  $A_c$**

**Circulation pumps** circulate the transport medium through the heating system. Up to date models run when heat is needed, whereas older models run continuously. The saving potential by replacement of the 18.1 mio. pumps can be up to 90% of the original required energy (per year and unit) and about 50% in average. About 52% of all circulations pumps used in Germany are older than 10 years. Furthermore those pumps are mostly over dimensioned. In addition to the saved electricity also 10-15% heat is saved, as rooms are not heat

unnecessarily. (Wohlauf, et al., 2005)

A case study by Grundfos emphasises that the real savings from a new circulation pump are bigger than the savings calculated based on the technical data. The average saving in the study was about double. (GRUNDFOS, 2011)

**Model representation: HyP**

The combination of all the ESMs above is also investigated. As not all ESMs are using definite numbers, the up to date values are used. The following Table 4 gives an overview over the values used:

**Table 4: Values used for the combined ESM**

ESM	4-7	11
value	U <sub>overall</sub> : 0.339 to 0.665 (g: 0.59)	80%

As measures 2-5 only apply for certain groups of houses Table 5 gives an overview of the grouping.

**Table 5: Building categorisation (SFD,MFD)**

Building ID	SFD	MFD
	X10-X29	X30-X511

As several measures mentioned above have similar effects on their fuelling system, namely the electric grid, their influence will be investigated together. Those aggregations of measures will be called packages, where the first package includes the reduction of demand for lighting, appliances and the circulation pump to the up to date level (Electricity I). The next package, called Electricity II) includes furthermore a heat recovery of 50% and a lowering of the average indoor temperature to 20°C. A further benefit from reduced electric consumption is smaller peaks in the electric grid and an unloading of the grid. This then reduces the emissions from the grid, e.g. for storage and back up capacity.

Also the insulation measures (PW4 – PW7) will be investigated as a package. This is due to the fact that such measures are state subsidised and are mostly carried out by one company.

An additional measure will simulate the upscale effect of a typical renovation, where besides new insulation also the furnace is renewed and a solar thermal system is introduced to the building. (Up to date I)

A more ambitious variation is the up to date II package, where it is assumed to make us of all the geo- and solar thermal potential. And the other fuels reduced accordingly to the 3.4.1. Also the higher efficiency of the gas boilers is considered (0.96) and a higher efficiency for oil boilers (0.94) due to exchange of the old furnace. Also an additional share of 2.5% of biomass fuels is introduced to the building stock. Even though this scenario seem quiet ambitious in the first place, the subsidies and cheap loans by granted by the government. (KfW)

### 3.4.2 Emission reduction by fuel change

The second group covers all the measures which are based on a change in fuel. This does not reduce the net energy demand of a building but can reduce the delivered energy demand of a building. In most cases high emissive fuels, e.g. oil and coal, are substituted by low emissive ones e.g. solar heating.

To cover the full scope of all energy sources available, one can start with the basic energy sources available. There are two energy sources which are infinite, with respect to mankind: the sun and geothermal energy.

Geothermal energy is making use of the temperature gradient along the radius of the earth. The extracted heat can be used directly for heating purposes (either space heating or warm water) by using downhole heat exchangers. Downhole processes can also be used to produce electricity, as their cycle transports big amounts of energy. The heat which can not be used for electricity generation can then be used for space and hot water heating. In areas with a low heat gradient in the surface near areas heat pumps can make use of the small temperature difference, by using a process similar to the one in refrigerators. This is constantly possible, as the temperature in about 6 m depth does not change significantly during the year. Also included in this group are heat pumps using air as a heat source, which is obviously not a geothermal source, but uses similar techniques and may thus be included in this group. The electric potential of geothermal energy is assumed to be  $6.4 \text{ GW}_{\text{el}}$ , which corresponds to  $50 \text{ TWh/a}$  (Klaus, et al., 2010). This potential considers ecological, financial and technical restrictions. Assuming such a plant delivers energy at a share of 50% heat and 50% electricity, gives  $6.4 \text{ GW}_{\text{th}}$ , which corresponds to  $50 \text{ TWh/a}$  heat (Geox)<sup>9</sup>. This heat, which would else be wasted, can then be used in a district heating system. On the one hand it must be argued that this heat is also partly used for commercial purposes, which are not covered here. On the other hand this reduction may be compensated by assuming that companies feed excess heat into a district heating system.

Besides this large-scale geothermal heat usage, one can also use the geothermal heat on a much smaller scale. This is done by heat pumps, which work in the same way as the ones to produce electricity. Only the scale and temperatures are different, as they only require much smaller amounts of heat and at lower temperatures. The following Table 6 shows the current installed heat pumps and the estimated potential in 2020. This potential is with respect to technical and economic aspects.

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<sup>9</sup> This geothermal power plant has the capacity assumed in the BMVS study and therefore the efficiencies can be used.

**Table 6: Installed and potential power of heat pumps (Platt, et al., 2010)**

Type	Av. heating power [kW]	Number installed 2008	Heat produced [TWh/a]	Installed power [GW]	Est. number installed 2020	Est. installed power 2020 [GW]	Est. heat delivered (2200 h/a) [TWh/a]
<b>Brine-water</b>	10	155,000	3.41	1.55	820,000	26.8	58.96
<b>Air-water</b>	12	88,000	2.32	1.056			
<b>Water-water</b>	14	26,000	0.8	0.364			
<b>Sum</b>	N/A	269,000	6.53	2.974	820,000	26.8	58.96

Adding up both measures this gives a total geothermal power of  $33.2 \text{ GW}_{\text{thermal}}$  and  $108.96 \text{ TWh/a}$  heat.

All the other energies, available for heating purposes, are due to the sun. The sun can be used either directly or indirectly. A form of direct use is the use of solar thermal panel. Those transfer the solar radiation into heat, which then can be used to heat spaces or to support warm water production. The potential for this is rather low, compared to other regions in the world, as the angle of the incoming beams of sunlight is rather flat. As already seen on the cover the available (direct) solar energy decreases from the South to the North of Germany. In 2012  $11.5 \text{ GW}_{\text{therm}}$  were installed. ((BSW-Solar), 2013) Future expected produced heat is  $36 \text{ TWh/a}$  in 2030, using  $99 \text{ mio. m}^2$  of collector area. (Ebert, et al., 2012). The area limitation is mainly due to shading and orientation of the roof areas. This potential will be introduced as a (renewable) fuel in the simulation.

The second way to make (rather) direct use of the sun is to convert the solar radiation into electricity. The same limitations apply as for solar thermal use. Photovoltaic is a direct competitor to the solar thermal energy, as the space available on roof tops is limited. Using other not used areas is done, but exceeds the scope of the thesis, as this is more a type of (micro) power plant, rather than a supporting energy source. Another often brought forward limitation of photovoltaic is the, compared to conventional fuels, rather unpredictable production and the unsteady availability. But it is shown that photovoltaic is no threat to the electric grid and thus shall not be discussed further here. The second argument, that the production is unsteady is partly right, but as the electricity is produced during high load times, photovoltaic even reduces the load on the electric grid during that time. (Burger, 2011) The total potential for Germany is estimated between  $161 \text{ GW}_p$  and  $275 \text{ GW}_p$ , which corresponds

to 66 TWh/a and 248 TWh/a respectively. The 66 TWh/a includes only a use of 34% of the available area, where the rest is given to the solar thermal use. ((BSW-Solar), 2013) and (Klaus, et al., 2010) This potential is not directly included in the model, as it is fed into the grid, but puts the electricity consumed (in the model) in a relation. The fed in into the grid influences the emissions of the electricity of the grid.

The third big group is biomass and waste. The combination of this group is based on technical reasons, as both can be burned as a solid or gasified. Also waste can be seen as a renewable source of fuel, as it will always appear. Also some components of that group are both, biomass and waste, e.g. wood chips from a saw mill. Biomass is a direct competitor, in terms of area, to food, which must be seen as a problem. The potential for biomass in Germany is also limited to the material use of biomass, e.g. wood for boards and beams. Also the potential for energy from waste, burned in a CHP and then supplied to the customers, can be seen as constant, as no further resources are available. One might argue that old landfills might be a source for 'new' waste (and other valuable resources), but this potential seems rather limited, as those landfills would need to be older than the introduction of the recycling system to have a sufficient energy potential. The sustainable biomass potential for Germany is estimated to 202 TWh/a, assuming an (slightly increased) CHP efficiency of 60% result in 121.2 TWh/a<sub>el</sub> and 80.8 TWh/a<sub>therm</sub>. This is a theoretical potential, which accounts all the potential available for energy production and not for material use. Excluding the use for other purposes, e.g. transportation etc., the potential is estimated to 23 TWh/a. (Klaus, et al., 2010) Other sources see the maximum potential for biomass already reached. (Nitsch, et al., 2010) This corresponds to the current data used in the ECCABS model. Thus further increase of biomass will not be investigated.

In this thesis the potential for biomass and waste will be limited to Germany, so no net imports are considered. It might be argued, that neighbouring countries, which have more capacities than they need, could supply Germany with biomass, e.g. Poland, Ukraine. This should be neglected anyways, as those transports require energy and the energy demand in those neighbouring countries will rise within the next years and thus they might be only able to supply for short terms. An area based perspective, rather than one restrained by political borders is to be applied, as only then optimal supply can be guaranteed.

**Model representation: P\_HP, P\_Sh\_X and P\_Hw\_X (corresponding to the added fuels)**

To get a better overview of the stated potentials above the following Table 7 will conclude this section:

**Table 7: Potential of the different renewable energy sources in private sectors**

Energy source	Potential [TWh/a]		Promising areas
	Electric	Thermal	
<b>Solar</b>	66	36	South
<b>Direct geothermal</b>	none	108.96	South and Rhine
<b>Biomass / Waste</b>	None	23	Rural areas
<b>Geothermal heat from electricity production</b>	50	50	Rhine
<b>sum</b>	116	217.96	

To get a better overview over the different potentials available in the different regions a bottom up characterisation seems to be ideal, as performed by the University of Technology Munich for the municipality of Ismaning. (Hausladen, et al., 2012) Thus a maximum supply with local renewable energies could be applied much easier, as they might be more easily implemented in the energy planning of to be build and renovated houses.

The other potentials, e.g. electricity from geothermal heat or biomass and waste, for energy exploitations may not be investigated in this report, as they are not applicable to the housing sector and may be seen as part of the German generation system. Nevertheless a sustainable exploitation of these resources reduces the greenhouse gas footprint of every dwelling, which relies on the (inter-)national grid.

### 3.4.3 Other measures

The third group of measures consists of those recommended by official and other sources, and the measures coming from the model itself. Those measures are mostly based on mathematical considerations and the sensitivity analysis of (Wanjani, et al., 2012). This subchapter will deal with the energy saving measures, which are obviously directly related to buildings, but can not be fully assessed with the ECCABS model. Table 8 gives an overview over these further measures, which are then described in detail.

**Table 8: Further energy saving measures**

Number	Measure
O1	Increase the share of wood in building materials
O2	Water management
O3	District heating
O4	Development area and population
O5	Update furnaces
O6	Reduced humidity
O7	Use wood based insulation material

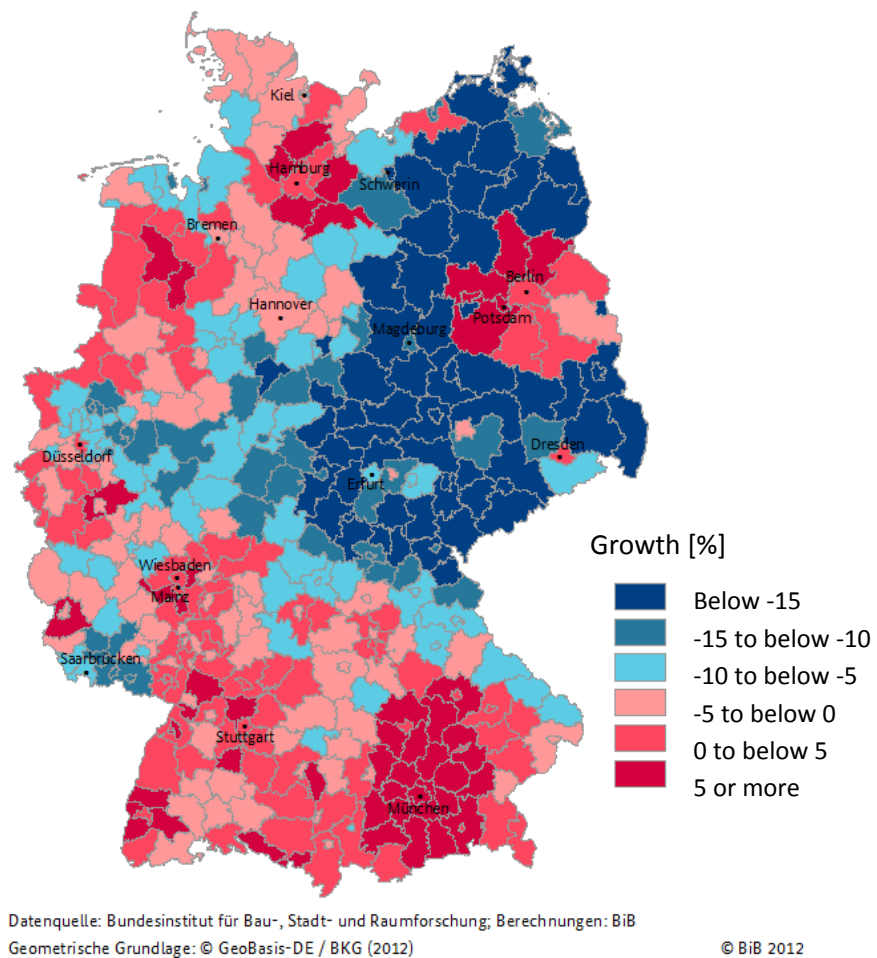
Buildings not only consume energy and emit GHG during operation, but also during construction (and the production of the materials used). Walls have a major share in buildings and thus account for a majority of the emissions during construction. The emissions<sup>10</sup> for 1 m<sup>2</sup> of conventional wall varies between 63 to 127 kg CO<sub>2</sub> equivalent, whereas wood based types vary between 42 to 54 kg CO<sub>2</sub> equivalent. (Die Nachhaltigkeit von Fassadenbaustoffen im Vergleich - Ökobilanz von zehn Außenwandtypen, 2012) In addition the wood stores 1 t CO<sub>2</sub> per 1m<sup>3</sup> and acts as a CO<sub>2</sub>-storage during the lifetime of the building.

Another interesting idea is the reuse of water within a building. As most such accommodations are built in the style of high-rise buildings, same floor plan for each level, the water used for showering or hand washing, may be used to flush the toilet of the next lower level (or even the own). The reuse of water across apartments can only be introduced in new buildings and, because of this not be further investigated in this thesis. The second one can be retrofitted to an existing bathroom.

As reuse of water, as described before, not only reduces the amount of fresh water used, but also along with that the energy used to pump water.

<sup>10</sup> including production, installation and end-of-life

The development of new housing areas is also a major potential, as a big movement from the city centers and rural areas, here especially eastern Germany, to the suburban areas is expected. The direct potential can be estimated by an interpolation between several housing standard models (EnEV 09, PHPP etc.). Along with those direct saving potentials also indirect potentials are available, e.g. by smart infrastructure, which allows short distances or good public transport for everyday ways. This reduces the emissions and energy demand, which are not directly reflected in the gas, oil or electricity bill. The change in population density (per county) is indicated in Figure 10 and shows the major potentials in and surrounding the major cities and the South of Germany.



**Figure 10: Population growth by county (2009-2030)**

Furthermore the total population of Germany is expected to shrink till 2050 to 71.5 mio.. This is a reduction of 12.6%. Thus the total energy demand for heating in Germany can be expected to decrease by that percentage.

Another measurement, which does not directly influence the demand of the building stock, but the primary energy demand (PED) is the increase of district heating capacity. A district heating system supplies a number of heat sinks with heat which are within certain distance. One of the advantages of such a system is that already over 20,000 systems have been set up. In 2011 those have supplied 344,412 customers/dwellings. The expansion and aggregation of those existing nets is estimated to 17.1 TWh/a, 84 TWh/a respectively. This numbers increase to 20.7 and 130.1 TWh/a by moving from a low price to a high price level and a changing from microeconomic to a (national) macroeconomic perspective. This difference, which is only due to economic reasons, might be bridged by government funding. The environmental benefit of such systems is that they are independent from the actual fuel and have an average

loss of about 12% in the net. (AGFW | Der Energieeffizienzverband für Wärme, Kälte und KWK e.V., 2012) This loss can be compensated by much more efficient furnaces. More often updated furnaces also give the possibility to adjust the fuel to local opportunities, with fewer restrictions due to the inhabitants, e.g. smell, technical skills, noise. This heat might be gained from wood chips, waste or other renewable fuels from a combined heat and power system (CHP). To assure a continuous supply, when needed, also fossil fuel can be burned (either in one furnace or more). Also the overall efficiency of the whole system, as only very little losses occur from the incineration, transport and transfer of heat to the dwellings, is rather high. Another advantage of such a system is that also other sources can feed in heat, e.g. from geothermal or solar thermal systems, or waste heat from nearby industries. Those potentials will be presented below. Some buildings can not directly benefit from local renewable sources, e.g. no geothermal source available or they are situated in a valley and can not use solar thermal energy. These buildings could then be supplied indirectly using a district heating system. Other obstacles could be unfavorable direction of the roof or monumental restrictions. Other arguments, brought forward in favor of district heating, are an easier handling for the customer, as heat itself is supplied. In addition the reduced number of total parts may also suggest a reduced total effort for the same amount of heat supplied. Furthermore the district heating requires much less space in the dwelling than a normal furnace, especially when considering also tanks. A benefit for the general public might be a reduced amount of effort in defrosting streets and sidewalks, as e.g. in Iceland.

The biggest advantage from an energy point of view is that only the heat is delivered, so furnace ‘growths and shrinks’ with the demand of the building, e.g. due to more inhabitants or a better insulation.

In this model the potential is combined with the one using **waste heat**, as they both use the same carrier system. Furthermore it is assumed that 50% is produced at the current price and emissions and 50% are waste heat, which are sold at the current price, but their emissions are already accounted.

#### **Model representation: P\_Sh\_DH and P\_Hw\_DH**

As already mentioned in chapter 3.3.2 Furnaces the vast majority of the furnaces used in German dwellings are outdated. A replacement of those, as the efficiency has increased, will reduce the demand for delivered energy, while the net energy demand stays constant.

As mentioned above, also the insulation material itself consumes energy produces and emissions during its lifetime. A change to wood based material can thus reduce the energy demand and corresponding emissions. It furthermore stores CO<sub>2</sub> during its lifetime. As the lifetime of insulation material is much longer than the one of fuels, an import will (over the lifetime) decrease the saved emissions only very little.

### 3.5 Environmental impact

As everything has an impact in its (direct) environment, also the energies used in dwellings have. As shown in Table 9 and Table 11 every form of fuel impacts the environment. To rate the different fuels and energy sources most often the CO<sub>2</sub> equivalent is used. In this report also the SO<sub>2</sub> equivalent is introduced.

#### 3.5.1 CO<sub>2</sub> equivalent

Similar to the merit order for power plants an order for fuels (for heating and hot water) is introduced. In contrast to the merit order, which is based only on the costs, this ranking is based on the emissivity, availability and the competing demands, e.g. used as material. This is important as only this allows comparing different measures against each other. This order is mainly based on the total emissions (per kWh), but also on the ability to substitute a certain fuel. The data is also taken from the GEMIS database, which was introduced in chapter 3.2 above. Fuel with a top rank will be replaced by fuel with a lower rank. The following Table 9 gives the ranking used and a short explanation, if the order differs from the emissivity.

**Table 9: Fuel substitution order**

Rank	Fuel	Emissions [g CO <sub>2</sub> -eq. / kWh]	Comment
1	Coal	330	Heavily subsidised in Germany and mining is determined
2	Electricity	579	Can hardly be stored and used for other purposes
3	Oil	313.5	
4	Gas	245	Emissions can be reduced by increasing the share of biogas or hydrogen; also a good energy storage
5	Biomass / waste	91.4	
6	District heating	251	Emissions can be reduced by change of fuel
7	Solar / geothermal energy	75 (photovoltaic), others neglectable <sup>11</sup>	

<sup>11</sup> CO<sub>2</sub>-Emissionen der Stromerzeugung - Ein ganzheitlicher Vergleich verschiedener Techniken, 2007

Another problem comes along with the use of gas, or to be more precise the methane in the gas. Its impact on the atmosphere is about 25 times more damaging than CO<sub>2</sub>. As methane is mostly not produced at the place of final use, it needs to be transported, in Germany mostly pumped through pipelines, to the place of combustion. The leakage during transportation is at the moment at about 36 g CO<sub>2</sub> equivalent / kWh. It must be argued that with increasing absolute amount, also the absolute emissions increase, but it must then also be considered that a local production of this gas reduces the losses, as they occur per km pipeline. (E.ON, 2005)

A further major discussable factor is the emission factor of biomass. They reach in literature from -575 to 100 g/kWh, which is due to the different assumptions. The negative values result from avoided methane emissions, which results from the natural decomposing of the biomass. (CO<sub>2</sub>-Emissionen der Stromerzeugung - Ein ganzheitlicher Vergleich verschiedener Techniken, 2007)

### 3.5.2 SO<sub>2</sub> equivalent

SO<sub>2</sub> is one of the main causes for acid rain, forest decline and acidification on foil. After the introduction of strippers in the late 1980's it went out of the public focus, as the impacts mentioned upfront declined rapidly. But nevertheless every combustion emits SO<sub>2</sub> and similar substances. The SO<sub>2</sub> equivalent, analogous to the CO<sub>2</sub> equivalent, rates the impact of different substances on the environment, as indicated in Table 10.

**Table 10: SO<sub>2</sub> equivalent (Staiß, 2003)**

Substance	SO <sub>2</sub>	NO <sub>x</sub>	HCl	HF	NH <sub>3</sub>	H <sub>2</sub> S
SO <sub>2</sub> equivalent	1	0.696	0.878	1.601	3.762	0.983

For the further calculations the following values for the different fuels are used (Life Cycle Umweltbilanz von österreichischen Heizsystemen, 2000) and (Zech, et al.):

**Table 11: SO<sub>2</sub> equivalent emissions of different fuels**

	Gas	Oil	Coal	Biomass	District heating	Electricity	Geothermal energy	Photo-voltaic	Solar thermal
SO <sub>2</sub> equivalent [g/kWh]	0.25	0.65	4	1.2	0.4	0.8	0.045	0.676	0.25

This value might either be used as another major indicator to rate heating systems, or as a secondary to decide between two CO<sub>2</sub>-equivalent wise similar options.

As well as for CO<sub>2</sub>-equivalent as for SO<sub>2</sub> equivalent emissions it must be kept in mind that those emitted by biomass are part of the regular cycle, whereas those from fossil have been stored and excluded from circulation for millions of years. These emissions have a high impact on the present climate. In contrast the biomass fuels add no quantities to the natural circulation.

### **3.6 Costs**

For the dwelling owner the costs and revenues are the major factor to either decide on applying a measure or not. The above investigated measures represent an update of a part of the current building stock. These can either be done by using less efficient materials or the measures only to a share of buildings. The first alternative is most unlikely to happen, as only investments in to an at least up to date level are made. As the discomfort is the same for the inhabitant, more efficient measures are chosen, if they return a cost saving. A applying of measures with up to date materials in just a part of the building stock, can be simulated by interpolating the different measures.

From a technical and national point of view especially the maximum potentials are of most interest and are thus investigated mainly in the following chapters.

An investigation of small, medium and big saving potential will show the relation between costs and saved energy and emissions.

#### **3.6.1 Measures**

Besides the measures summed up in the pathway project, also the costs for retrofitting the whole envelope are investigated. This is due to the fact that such massive renovations are aggregated and it is made use of synergies. Furthermore some components (e.g. furnace) of the new energy system must be dimensioned according to other parts (e.g. insulation). In addition those measures with the biggest reduction in emissions and delivered energy are considered.

The costs for certain measures are marginal costs. This is due to the fact that nearly all of the energy renovations will be done when a ‘cosmetic’ renovation or a replacement due to failure is performed. The costs for the measures to save electricity from appliances and lighting are set to 0 as well, as EU regulations ban more and more inefficient products from the market, as stated above.

The costs for certain measures were mostly taken from the *Schwäbsich Hall* bank, which finances housing related projects, as renovations. If not indicated other.

The costs for packages are the sum of all individual measures, so synergies are not accounted for. As measures have different lifetimes, the costs for each sub-measure was up scaled to the lifetime of the longest measure, mostly the insulation with 40 years.

### **3.6.2 Maintenance**

The maintenance costs for buildings and its components depend much on the age of the building, its construction complexity and the type of building.

As the calculated values are average across the whole building stock also average values for maintenance must be applied. Also no inflation needs to be considered, as it is calculated with respect to the reference year 2009.

The effects of the age of a building may be neglected in this case, as a whole building stock is investigated. So the lower costs for newer houses compensate for the one of older dwellings. Same applies for the maintenance increase due to the complexity of construction, e.g. dormers. This is reasonable, as the whole building stock includes as well timbered houses, with a rather high complexity, as prefabricated houses with very simple designs.

As maintenance costs are, among others, due to the roof, furnace etc., and will be expressed per m<sup>2</sup>. So a big house, which has more m<sup>2</sup> per roof and furnace, has lower maintenance costs. The costs are 8 €/m<sup>2</sup>\*a and 10 €/m<sup>2</sup>\*a respectively. (Schmidt, 2006) and (Ollenik, et al., 2011)

As those costs occur nearly independent of the measures applied, they will be set to zero. In the cost analysis the additional costs for maintenance, which can also be negative, will be considered. Those maintenance costs are mostly made up of costs for reparations, inspections, investments and insurances.

### **3.6.3 Variables and fixed values for the cost analysis**

The costs for the different measures depend on a number of variables. Along with the prices for the different fuels, also the taxation, the utilised capacity of the companies and scaling effects, e.g. during production, are influencing the final costs.

In addition the (direct) costs for the inhabitant or owner, who is allowed to pass on some of the costs to the lessee, will be influenced by subsidies. Those subsidies will not be taken into account in that investigation, as they vary rather easily with political will and have to be paid by the inhabitant (or owner) in the end in forms of taxes. Also the taxes on the goods and services will be assumed as stable, as they only depend on the current (fiscal) political situation. As the price for the different fuels are a major driver of the financial payback time and hard to predict a sensitivity analysis will be performed.

The costs which are associated with the different measures presented above are costs which will be carried to the account of the owner (or investor) of the dwelling. As the cost

reductions, e.g. for hot water or space heating, disburden the inhabitants, this conflict of interest appearing in rented out dwelling needs to be addressed properly. But also another aspect, taking a broader view, needs to be taken into account, the costs for the population, which are not directly billed with the energy bill. The European energy agency (EEA) estimates these costs, for the 68 biggest German energy plants (by direct emissions) to 18.4 billion €, only in 2009. In the whole European Union those costs associated with the biggest polluters in the energy sector account for about 66% of all registered costs due to emissions. (European Environment Agency (EEA), 2012) These costs must be taken into account as well, as they have to be paid by the inhabitants as well, e.g. as health insurance premiums. Assuming a reduction of this costs by 25%, by cutting back the energy demand accordingly, gives a sum of about 4.6 billion € for investments per year.

The following Table 12 gives an overview of the assumed economic parameters and their ranges of investigation.

**Table 12: Economic parameters**

Parameter	Number of discounted years	Discount rate energy savings	Discount rate (investments)
Abbreviation	N	R	r
Default value	1	0.04	0.03
Range	none	none	0.01, 0.04, 0.1, 0.8, 0.4

The high discount rates ( $r > 0.04$ ) are not real interest rates, they are a measure how willing the investor is to invest. The higher they are the harder is it on a personal level to do the investment.

The following Table 13 gives an overview over the costs and lifetimes assumed in this thesis. The maintenance costs are calculated according to the EN 15459:2006 as a percentage of the investment costs alike the lifetimes (except for appliances).

Table 13: Costs and cost related data

Measure	Maintenance (M_EA) [€/a]	Costs per heated floor area [€/m <sup>2</sup> *a]	Costs above ground [€/m <sup>2</sup> *a]	Costs below ground [€/m <sup>2</sup> *a]	Costs for window [€/m <sup>2</sup> *a]	Costs for roof [€/m <sup>2</sup> *a]	Costs per building [€/bldg.*a]	Lifetime n [a]
Thermostats <sup>12</sup>	10.40	0	0	0	0	0	260	15
Ventilation SFD <sup>13</sup>	2.40	60	0	0	0	0	0	20
Ventilation MFD	1.60	40	0	0	0	0	0	20
Hot water SFD	0	0	0	0	0	0	4500	20
Hot water MFD	0	0	0	0	0	0	4500	20
50% appliances	0	0	0	0	0	0	0	8
Circulation pump <sup>14</sup>	0	0	0	0	0	0	175	20
50% lighting	0	0	0	0	0	0	0	2
Up to date insulation	0	32.53	353.85	30.77	107.69	153.85	0	30
All (above) ESMs	32.53	200	0	0	0	0	10043.33	40
Solar thermal	53.50	0	0	0	0	0	7500	20
District heating <sup>15</sup>	-220	0	3.92	0	0	0	0	20

<sup>12</sup> Assuming 1 radiator per 15 m<sup>2</sup> and 130 m<sup>2</sup>/dwelling and 30€/radiator

<sup>13</sup> Taken from <http://www.heizungsfinder.de/heizung/wohnraumluftung/kosten> (as of 20<sup>th</sup> April 2013)

<sup>14</sup> Taken from <http://www.heizungsfinder.de/heizung/umwaelzpumpe/preis> (as of 20<sup>th</sup> April 2013)

### 3.7 Sensitivity analysis

As mentioned above the economic aspect, which is the major aspect for housing owners, is depending on the energy prices. They can rise (or more unlikely fall) due to changes in demand and supply, but also due to changing taxation. The taxation could be lowered to support the (national) economy or raised to change final consumer behavior (Pigovian tax).

The sensitivity analysis will focus on the economic output variables, as they are most interesting for the success of the projects. The results shown in Table 14 will be investigated as they give a number to compare different measures. The measures can be grouped into two. The first one considers all measures, whether they are economically feasible. The second sums up only the measures which have a positive economic result. So the measure is cost efficient and the consumers actually save money.

**Table 14: Outputs economic analysis per year**

Output	Unit	Abbreviation
Weighted average energy costs	€	WAvg.EAC
Weighted average savings	€	WAvg.S
Weighted average saved net energy	kWh	WAvg.SNetE
Weighted average saved emissions	t CO2-eq.	WAvg.EmS
Total saved delivered energy	TWh	TotSDeIE
Total saved emissions	Mt CO2-eq.	TotEmS
Weighted average energy costs	€/kWh	WAvg.CE
Weighted average abatement costs	€/t CO2-eq.	WAvg.AC
Cost efficient total saved delivered energy	TWh	Cef TotSDeIE
Cost efficient total saved emissions	Mt CO2-eq.	Cef TotEmS

<sup>15</sup> City council of Frankfurt /Main  
(<http://www.frankfurt.de/sixcms/media.php/738/Fernw%C3%A4rme%20Wirtschaftlichkeit.pdf>)

The sensitivity analysis will investigate the changes in the output by a 1% change ( $\Delta k_j$ ) in the input and put it into relation, as follows.

$$\frac{\partial y_i}{\partial k_j} \approx \frac{y_{i(k_j+\Delta k_j)} - y_{i(k_j-\Delta k_j)}}{2\Delta k_j} = 1, \dots, n \text{ and } 1, \dots, m \text{ (with } n = m = 2)$$

Multiplied with the fraction of the input values this gives the sensitivity coefficient.

$$S_{i,j} = \frac{k_j}{y_i} \frac{\partial y_i}{\partial k_j} = 1, \dots, n \text{ and } 1, \dots, m$$

This sensitivity coefficient indicated how sensitive the output reacts to a change in the input. Or in this case how sensitive the different economic outputs are to changes in prices and discount rates.

## 4 Results

The following chapter will present the results obtained from the simulations by introducing the different ESMs and combinations of those. For a better understanding of the savings the baseline simulation is presented.

The energy consumption is rather easy to put in relation to, as energy bills have to be paid by most of the persons. In contrast the emissions are rather hard to illustrate, as there is no figure in general discussion. Never the less some numbers shall be stated here to give the reader an idea of proportions. The German average emissions vary between 11 and 15.73 t CO<sub>2</sub>-equivalent per year. The UBA calculated the maximum acceptable emissions (in CO<sub>2</sub>-equivalent) per person and year to 2.5 t.<sup>16</sup>, of which already 1.1 t CO<sub>2</sub>-equivalent per year are due to general services, which leaves 1.4 t/a for all other areas. Currently 2.47 t CO<sub>2</sub>-equivalent are accounted for housing annually. ( (UBA) and (Carbon Footprint of Nations: AGlobal, Trade-Linked Analysis, 2009)).

### 4.1 Validation of the model

As the model is based on several different datasets and assumptions the validation by comparison with other data is crucial.

In a first step the baseline is compared to a range of different models, as shown in Table 15.

**Table 15: Final energy demand for 2009 [TWh/a]**

	ECCABS model	Wanjani & Bauer	DESTATIS	Ger. Ministry of Economy	Eurostat
Space heating	561.64	560.66	492	498.03	553.57
Lightening	7.94	7.94	11	-	-
Appliances	58.07	58.07	60	-	-
Hot water	59.36	59.85	82	-	-
Circulating pumps	11.46	11.46			
Total	698.47	697.98	680	688.32	765.09
Variation of total [%]	0	0.07	2.65	1.49	-9.68

<sup>16</sup> This number is based on the maximum total emissions allowed to just reach the 2°C goal in 2050, as internationally agreed on.

The results vary between 2.65% and -9.68% compared to the other data found. The EUROSTAT result is the only one bigger and by far more divergent from the others.

## 4.2 Baseline results

### 4.2.1 Current demand and shares

The baseline scenario represents the current state of the German building stock, with respect to the energy demand. Against this scenario the following ESMs will be benchmarked. This comparison allows to not only compare the total energy demand, but also with respect to archetype, fuel and other criteria.

The baseline results in a net energy demand of 670.53 TWh/a and a delivered energy demand of 693.26 TWh/a. These demands can be described briefly as follows in Table 16:

**Table 16: Energy demands of the baseline by fuel and building type**

Archetype	1	2	3	4	5	6	7	8	Total demand
<b>Electricity</b>	34.68	13.06	32.01	11.04	0.12	0.46	1.71	0.52	93.6
<b>Oil</b>	62.03	16.47	80.73	25.89	0.47	1.74	2.34	1.31	190.98
<b>Gas</b>	85.2	22.1	104.42	31.29	0.57	2.4	3.63	1.68	251.29
<b>Biomass</b>	34.85	8.69	43.87	13.27	0.26	0.97	1.05	0.68	103.64
<b>Coal</b>	1.25	0.33	1.8	0.6	0.01	0.03	0.02	0.03	4.07
<b>District Heating</b>	6.93	1.8	8.66	2.65	0.05	0.19	0.27	0.14	20.69
<b>Solar</b>	0.94	0.25	1.18	0.36	0.01	0.03	0.04	0.02	2.83
<b>Others</b>	0.61	0.44	1.37	0.92	0.01	0	0.05	0.03	3.43
<b>Total</b>	226.49	63.14	274.04	86.02	1.5	5.82	9.11	4.41	670.53

This corresponds to 323.2 Mt CO<sub>2</sub>-equivalent and 13.67 Mt SO<sub>2</sub>-equivalent in emissions.

A more detailed table, including the demands for every building class can be found in the appendix.

#### 4.2.2 Different insulation standard scenarios and corresponding fuel shares

The different energy efficiency standards for houses, introduced in 2.2.3, result in different total energy demands for the German building stock, as indicated in Table 17. As the potentials, introduced in chapter 3.4.2 above are not depending on the energy demand of the building stock, but are static. As a consequence the shares of net energy demand they can cover varies:

**Table 17: Different energy demands and corresponding fuel shares**

<b>Standard</b>	<b>Total net energy demand [TWh/a]</b>	<b>(Direct) geothermal heat [%]</b>	<b>Solar heat [%]</b>	<b>Geothermal waste heat [%]</b>	<b>Share renewables<sup>17</sup> [%]</b>
<b>Current</b>	693.24	15.72	5.19	7.21	28.12
<b>EnEV 04/07</b>	668.69	7.48	5.38	16.29	29.16
<b>EnEV 09</b>	369.07	13.55	9.75	29.52	52.82
<b>Up to date</b>	374.26	29.11	9.62	13.36	52.09
<b>PHPP</b>	302.9	35.97	11.89	16.51	64.36
<b>Total potential</b>	N/A	108.96	36	50	N/A

<sup>17</sup> Not including biogas as renewables

### 4.3 Results for ESMs mentioned in the pathway project

In the following section of the report the major findings of the different ESMs will be presented. These include the total energy demands, emissions and shares of fuels. In addition major contributors will be identified, both positive (+) and negative (-). Where a sensitivity analysis was done the net energy demand and delivered energy demand is plotted.

#### 4.3.1 Use of thermostats to reduce average indoor air temperature

The reduction of the indoor temperature must not be mixed up with the temperature the inhabitants experience inside the dwelling. The temperature modeled is an average value, also including less or not heated areas (e.g. basement, sleeping areas, storerooms etc.). It is also an average over time, so including working hours or vacation, when no heating is required. Up to date heating systems can be programmed to heat the dwelling in such way that it is warm during the morning, evening and weekend. Thus average indoor temperatures are below the temperatures considered comfortable for living areas and such.

The reduction of the average indoor temperature is applied by allowing lower indoor temperatures, before the heating is started.

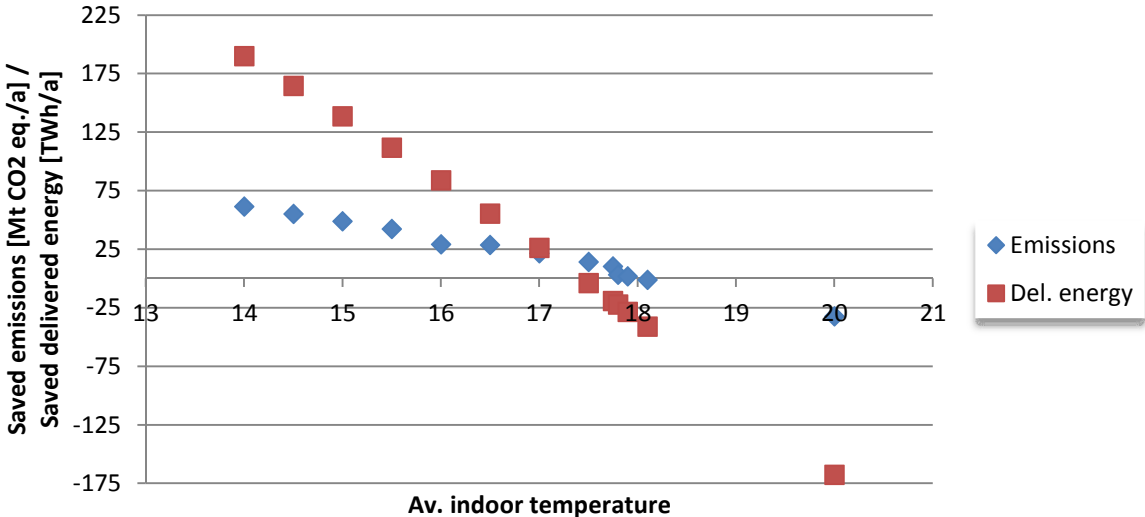


Figure 11: Saved delivered energy depending on the average indoor temperature

The simulation shows that any reduction of the indoor temperature will reduce the emissions and below 19.6°C also the demand of delivered energy will decrease. The reductions represent between 29% and 4.8% of the total emissions and 3.7% to 27.2% of the delivered energy of the baseline scenario, see Figure 11.

These reductions will be even bigger by allowing different acceptable indoor temperatures for different month, as the clothing changes over the year.

### 4.3.2 Ventilation with heat recovery (SFD and MFD)

In this method the heat recovery is applied in all buildings from the type SFD/TFD and RH. This grouping is not only based on the geometry, but also on the ownership of such building. Those buildings are mostly owned by the inhabitants or rented directly and can such be grouped together. In addition their style of construction is rather similar.

The maximum total heat recovery is 50% (Juodis, 2005). The simulation is varied between 5 and 50% of maximum heat recovery, to simulate the different efficiencies and spreading across the building stock, as indicated in Figure 12 and Figure 13.

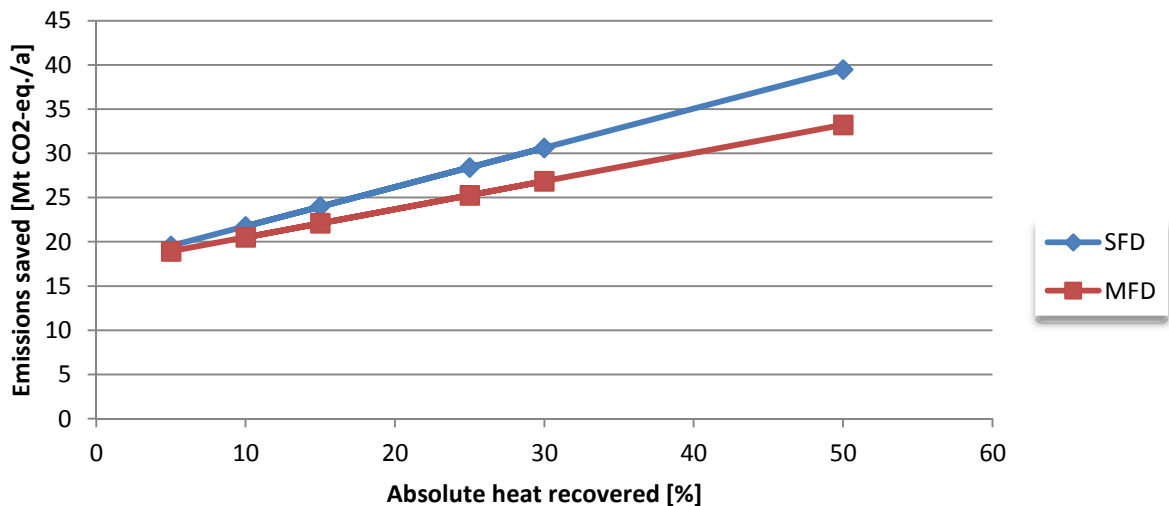


Figure 12: Emission saving potential ventilation

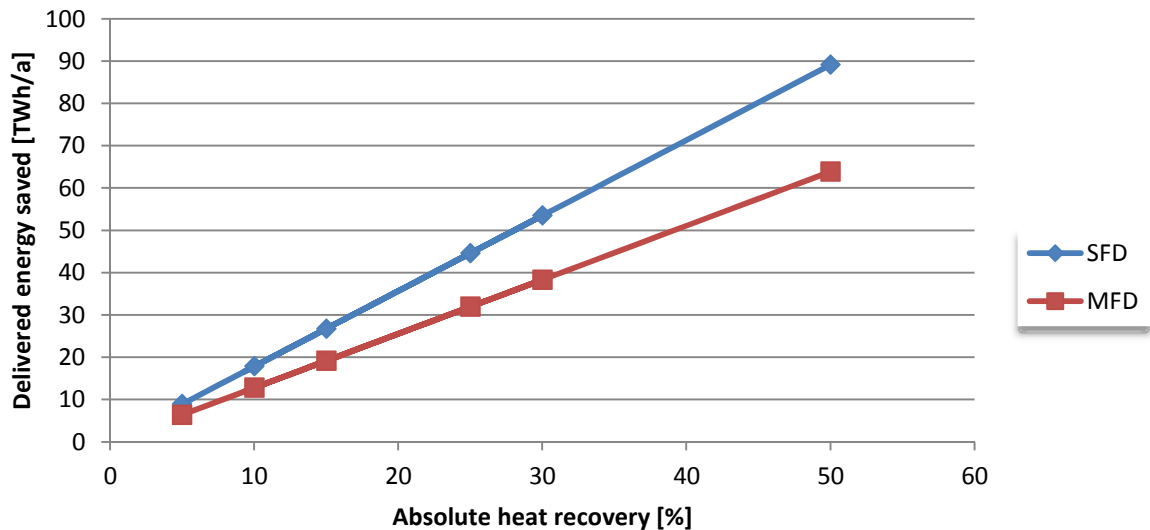


Figure 13: Delivered energy saving potential ventilation

### 4.3.3 Increase of insulation of the envelope

The (outer) envelope of a building consists of 4 different parts, as mentioned before. The insulation of windows, attics/roofs, facades and floors are often implemented simultaneously, but from an investment point of view the different measures compete against each other. Illustrating all savings in one diagram allows to compare the effects of the different measures and for different intensities.

Newer windows not only have a reduced U value, but also a reduced transmittance (g value). This value represents how much (solar) energy is transmitted into the building through the window. The values for the different subtypes was given, but as newer windows have a reduced U value and a reduced transmittance this value was updated in the input file, as shown in Table 18 below. The simplification for high U values is based on the assumption that the total number of windows changed to achieve is negligible compared to the lower values, where nearly all windows of several classes must be changed.

**Table 18: U values for windows and their corresponding g values used for the different measures (Jagnow, et al.)**

U value	4 to 1.7	1.7	1.3 and below
g value	given	0.59	0.49

To improve the average envelope and to investigate the effect of that, the maximum allowable U value for every part of the envelope was reduced. This means that e.g. the average windows must not have a U value higher than 3. This method allows to upgrade only the ‘worst’ parts. Figure 14 and Figure 15 indicates the saving potential for the different parts of the envelope and the different reductions in U value.

The local minimum in Figure 14 for windows at  $U=1.7 \text{ W/m}^2$  results from a significant number of changes of windows. From  $1.7 \text{ W/m}^2$  and below much more windows must be changed and the g value must thus be adjusted accordingly.

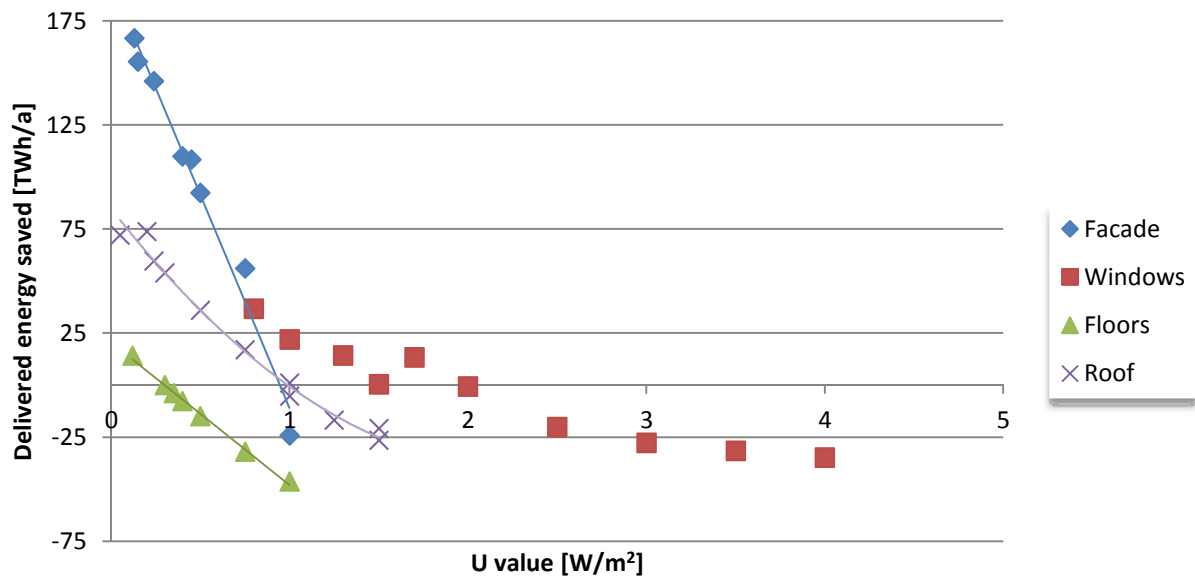


Figure 14: Energy saving for different U values and different components

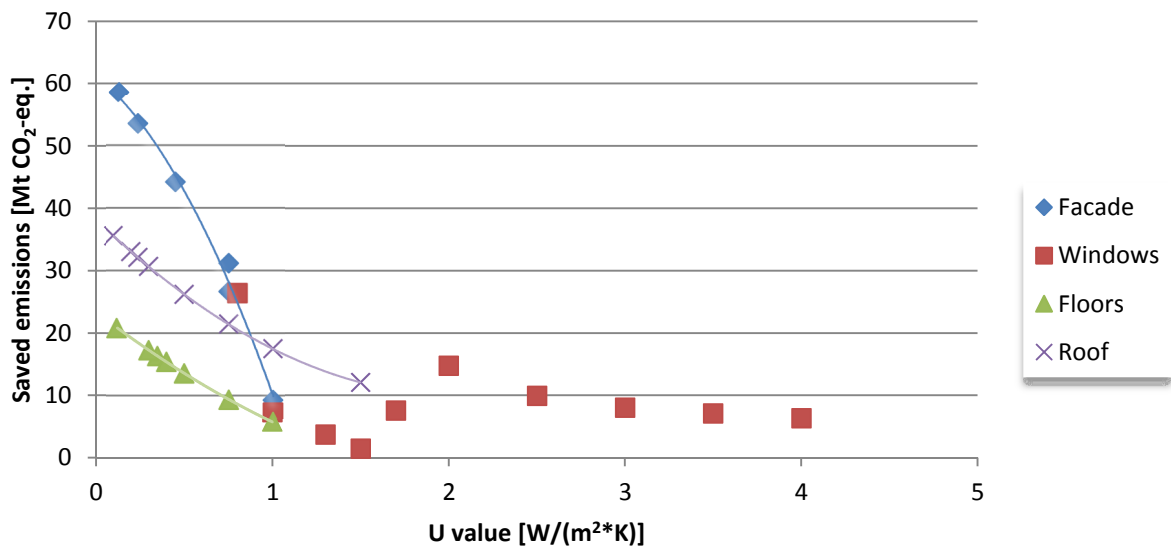


Figure 15: Emissions for different U values and different components

As nearly any combination of the replacement of parts of the envelope is possible, a complete turnover of the envelope is investigated. This can also be motivated as the measures are applied simultaneously, as then several synergies can be used. The different used values correspond to the ones required by the  $K/W$ . For better comparison the delivered energy demands are also given for the current housing stock and an update to the current technical state of the art (see Figure 16) and the corresponding emissions (see Figure 17).

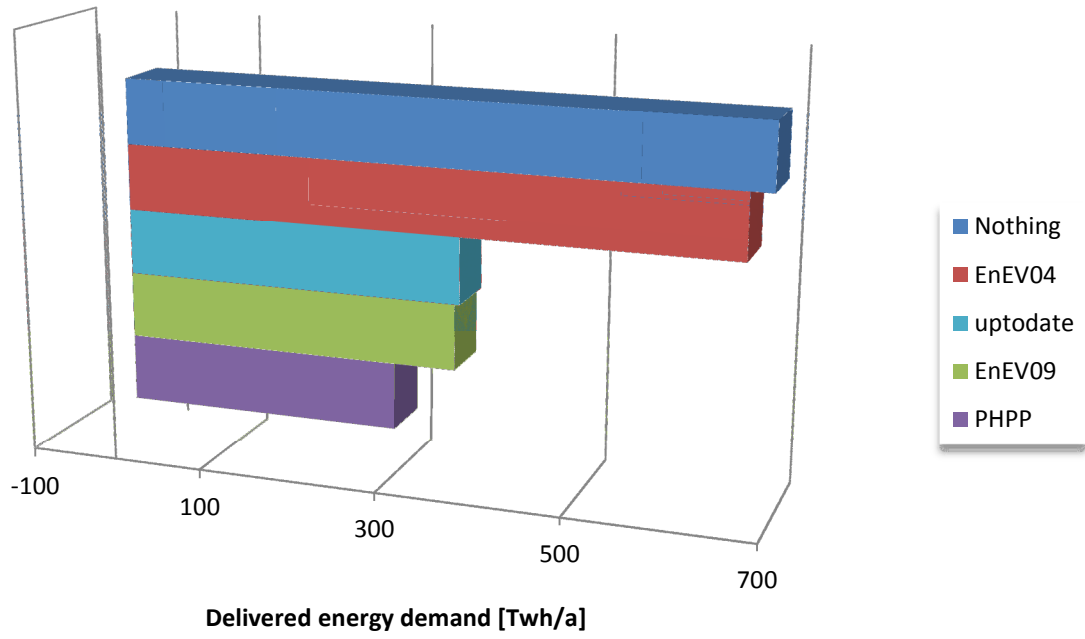


Figure 16: Delivered energy demand using different envelope insulation standards

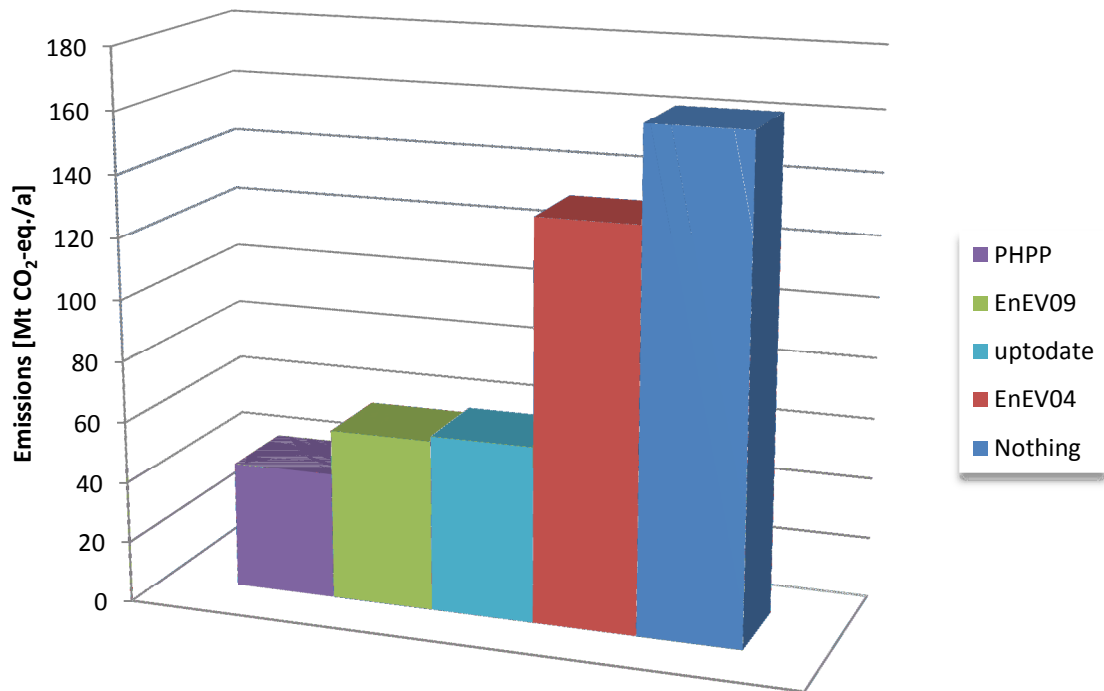


Figure 17: Total emissions applying different envelope standards

### 4.3.4 Reduction of power used for hot water production

The energy demand for hot water does not only depend on the amount of hot water consumed, but also on the efficiency the fuel is converted in to heat and then the heat transferred to the water. As mentioned above the habits are not discussed and thus only a more efficient hot water system is investigated.

The following Figure 18 shows the influence on energy demand and emissions of different average power demands for hot water productions in the whole building stock.

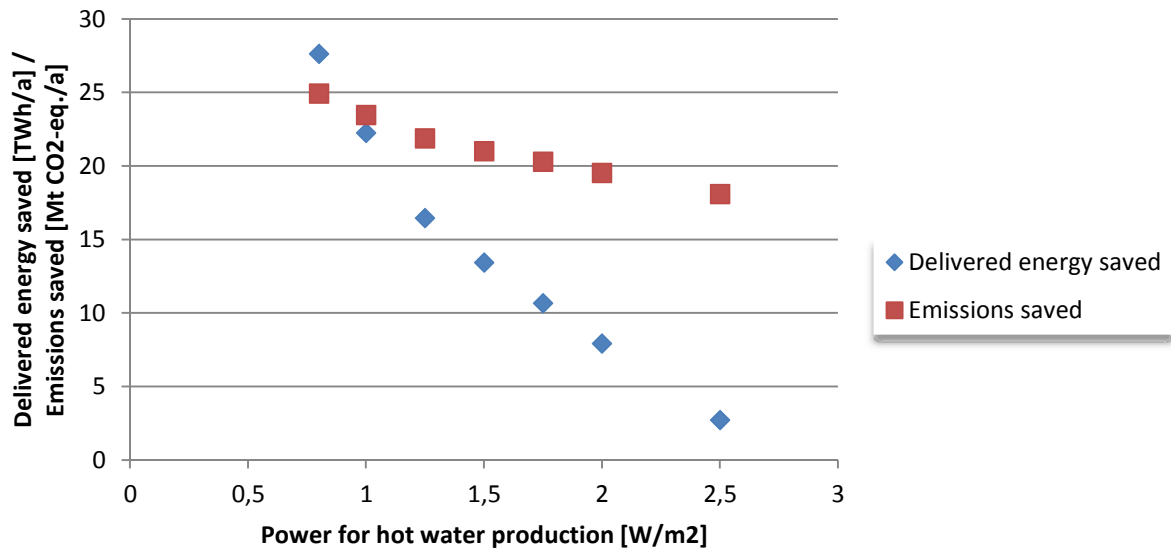


Figure 18: Saving potential for hot water production

The production of hot water is either combined with the heating system or individually for every flat. In the first case a renewing can only be done in combination with the appliance for space heating.

The reductions for the specific measures investigated in the pathway project are as indicated in Table 19.

Table 19: Savings hot water production

	Saved Emissions [Mt CO <sub>2</sub> -eq./a]	Saved delivered energy [TWh/a]
<b>SFD (0.8 W/m<sup>2</sup>)</b>	15.63	46.71
<b>MFD (1 W/m<sup>2</sup>)</b>	20.03	59.01
<b>Total</b>	35.66	105.72

#### 4.3.5 Reduction of power used for appliances, lighting, circulation pumps and packages

The grouping of these measures is not only based on their demand for electricity, but also that they are already subject to current EU regulations. As a result of that an increase of highly efficient appliances can be assumed, as the low efficient versions are taken off the market.

The heat gains from lighting are varied between 100% and 20% of the initial value. This corresponds to a use of 0 to 100% compact fluorescent lamp (CFL) or a corresponding reduction in comfort or wasting. An alternative would be to substitute electric lighting by lighting with 'light tubes'<sup>18</sup> or similar measures. As already an increasing share of CFLs is in use, the reduction in demand must be achieved by a combination of all 3 opportunities.

Similar applies for the heat gains from the heat pumps and other electrical appliances.

The graph for the circulation pumps can be seen as a share of high efficient pumps, as there are only rather low or highly efficient models available on the market.

As indicated below the savings follow a linear trajectory (see Figure 19 and Figure 20).

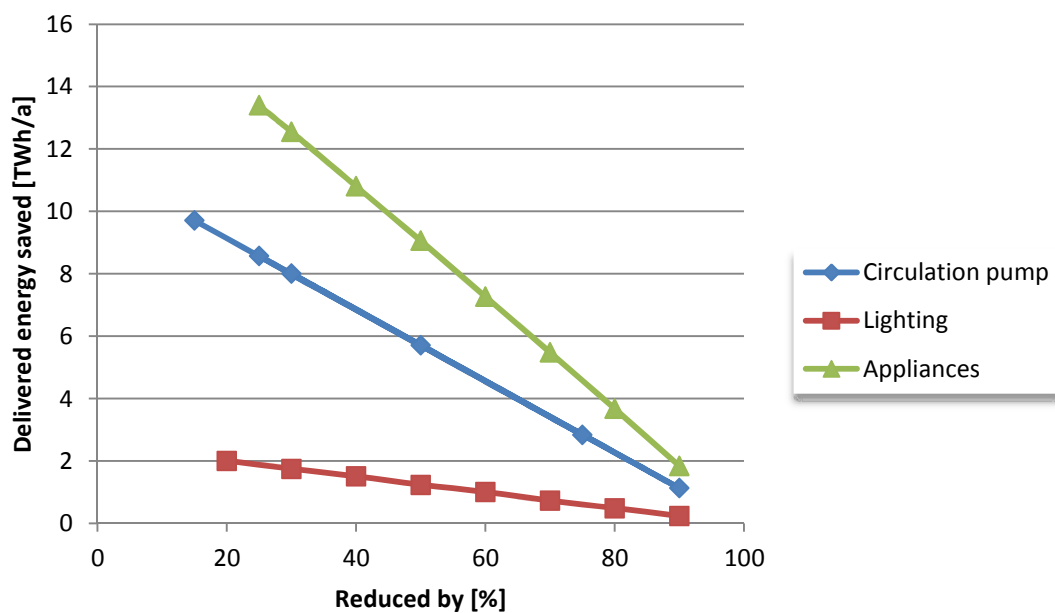
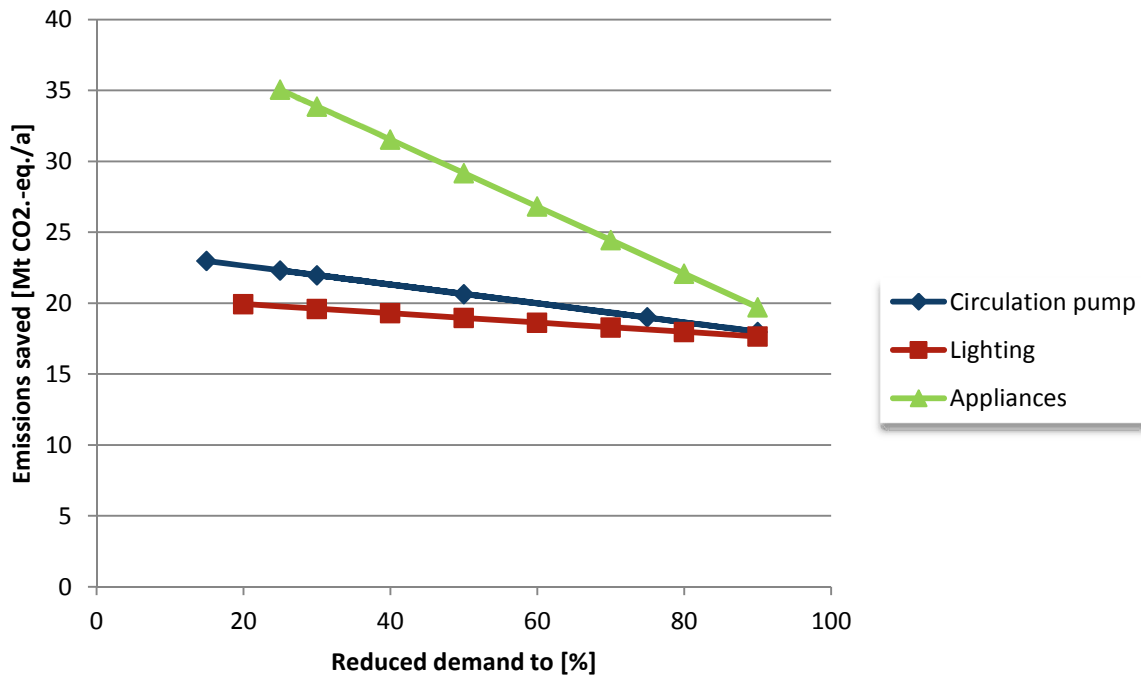


Figure 19: Delivered energy saving from different electrical appliances

<sup>18</sup> Light tubes collect sunlight at the outside of a building, e.g. roof, and transport it to the inside, using polished pipes. Those systems are featured with conventional lighting, to always supply sufficient brightness.



**Figure 20: Emissions saved from different electrical appliances**

By bringing all 3 groups of electric devices to an up to date standard, namely the Electricity I package, 20.01 TWh/a delivered energy could be saved. This corresponds to a saving of 70.83 Mt CO<sub>2</sub>-eq./a in emissions.

The Electricity II package would save 172.72 TWh/a in delivered energy and 56.84 Mt CO<sub>2</sub>-eq./a.

The renovation of the whole building stock to an up to date insulation standard and a new solar supported boiler would save 341.26 TWh/a in energy and corresponding 85.27 Mt CO<sub>2</sub>-eq./a.

The ambitious upgrade of the heating system, up to date package II, would save 47.25 TWh/a and 28.24. This already shows the high influence of the insulation standard.

The combination of all measures summarized in the pathway project has a total reduction potential of 158.77 Mt CO<sub>2</sub>-eq./a and 580.3 TWh/a. The following table gives an overview of the individual pathway measures and the combined.

Table 20: Comparison of pathway measures

Measure	Saved Emissions [Mt CO <sub>2</sub> -eq./a]	Saved delivered energy [TWh/a]
Thermostats	16.36	1.2
Ventilation	44.61	109.1
Hot water	23.77	70.1
Insulation	101.87	354.7
Electric appliances	71.24	35.8
<b>Sum</b>	<b>257.85</b>	<b>570.9</b>
<b>All ESMs at once</b>	<b>158.8</b>	<b>580.3</b>

The following Figure 21 compares the effects of the different packages.

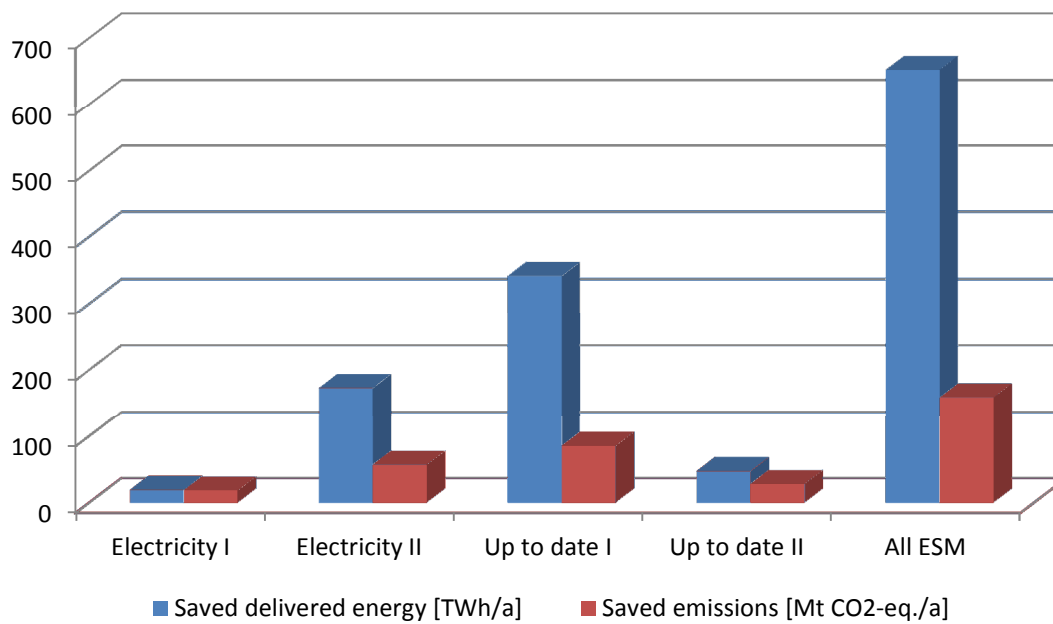


Figure 21: Savings of the different packages

#### 4.4 Results for emission reduction by fuel change

As pointed out above the emissions can also be reduced by a change in fuels. Whereas the term fuels takes wider approach including also solar and geothermal heat gains. Such fuel changes do not change the net energy demand of the building, but can change the delivered energy demand.

The introduction of the maximum potential of solar and geothermal heat into the existing building stock results into the following emission savings (see Figure 22)<sup>19</sup>:

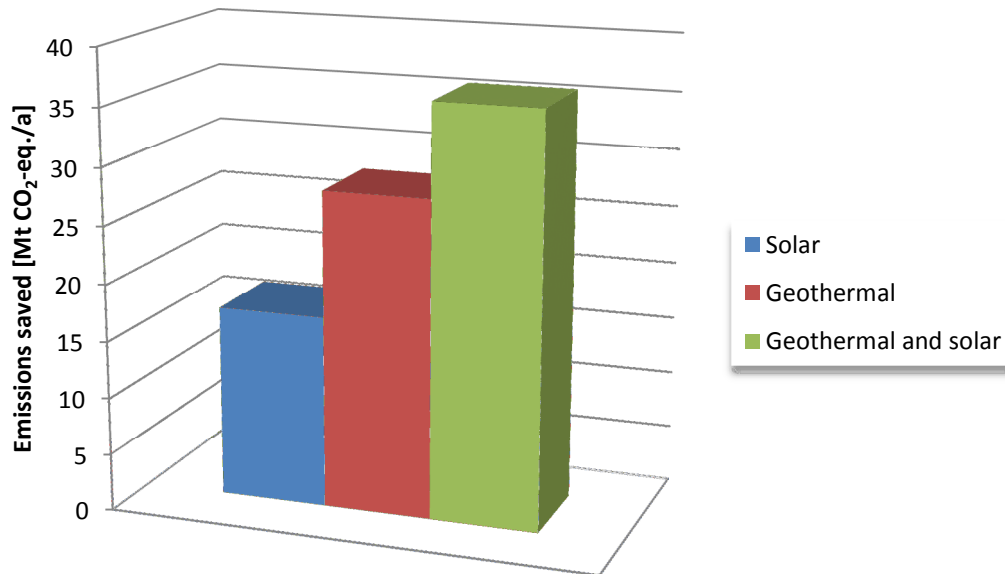


Figure 22: Emission saving potential in the current building stock using solar and geothermal heat

By substituting oil for biomass the emission saving indicated in Figure 23 can be accomplished:

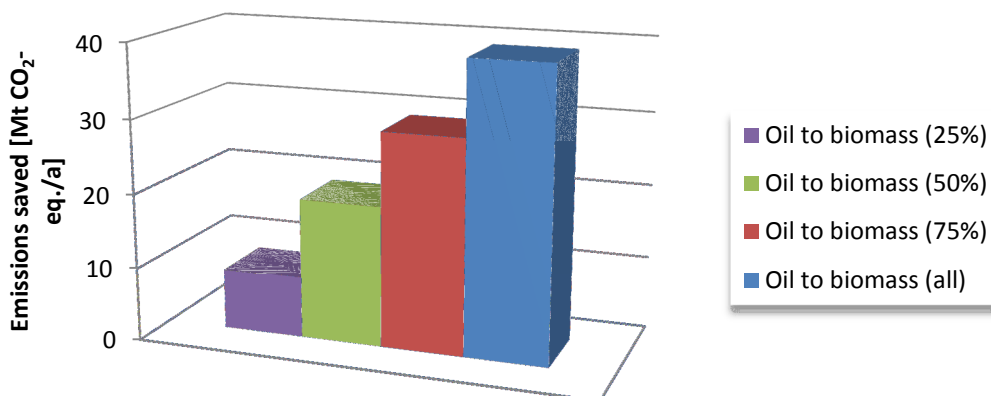


Figure 23: Emission saving potential from oil to biomass substitution

<sup>19</sup> The solar and geothermal heat substituted the other fuels by the order given in Table 9.

The order given in chapter 3.5.1 CO<sub>2</sub> equivalent above also suggests a changeover from oil, coal and electricity to natural gas. This corresponds to the trend of the last years in the housing stock, where mainly gas furnaces were used. The outcome of such a makeover is shown in Figure 24.

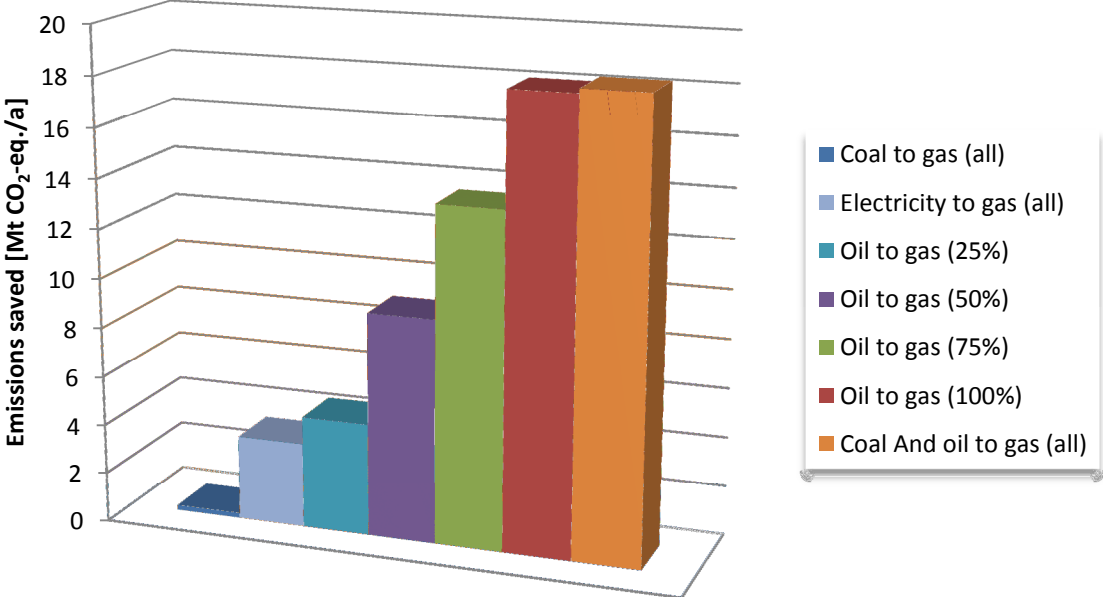


Figure 24: Change over to gas

### 4.5 Results for the further investigated measures

As indicated in chapter 3.3.2 Furnaces the boilers and furnaces used in the German building stock are mostly outdated. A simple change of those boilers would increase the average efficiency and thus reduce the delivered energy demand and the emissions (see Figure 25 and Figure 26).

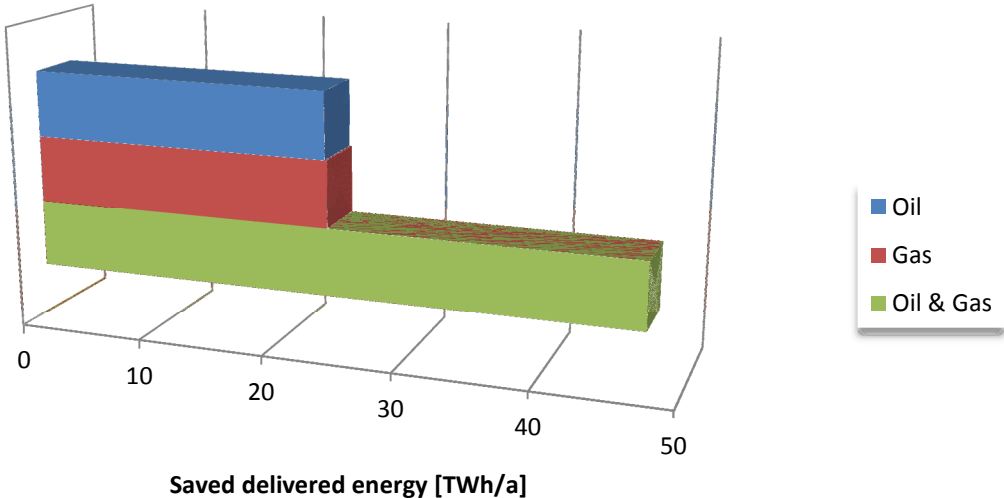
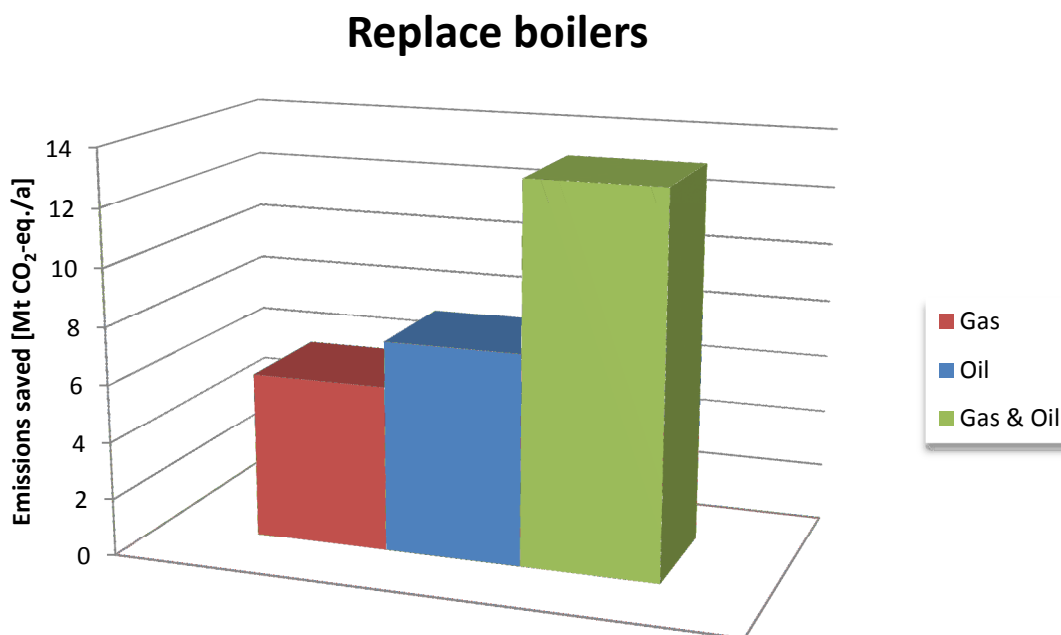


Figure 25: Saved delivered energy by furnace update



**Figure 26: Emission reduction by update of boiler**

The in practice found improvements of the furnace replacements will be higher than the theoretically calculated ones, as the new furnace will fit the demand of the specific dwelling more accurate.

The introduction of further district heating into the German building stock reduces as well the delivered energy, as the emissions: 14 TWh/a and 13.3 Mt CO<sub>2</sub>-eq. respectively.

The energy and emission savings from efficient planning and construction of new building areas of the dwellings can be estimated by interpolating the results for a makeover of the total building stock. It can be assumed that this is represented by the population if the new states (*Neue Bundesländer*), which corresponds to 15% of all populations (DESTATIS) and thus houses, see Figure 10. They are subject to such planning within the next 50 years. Adapting the results from chapter 4.4 a saving potential between 6.9 and 17.1 Mt CO<sub>2</sub>-eq. can be predicted. The savings from sustainable building, reduced transport and others are not included.

The potential of the emission and energy saving by the insulation material can be calculated by the total outer area (floor, roof and facade) and the data given in Table 24. The saving potential can be estimated to be between 633 and 1,145 TWh (depending on the share between PU and mineral fibre), which corresponds to about 6,793 Mt-CO<sub>2</sub>-equivalent<sup>20</sup>. A 40 year lifetime for the insulation gives an annual saving of 169.8 Mt CO<sub>2</sub>-equivalent. The potential to store CO<sub>2</sub> can be estimated to 2,708 Mt-CO<sub>2</sub>(-equivalent) A detailed calculation can be found in chapter 9.4 below.

<sup>20</sup> Whereas the emissions for a wood chip based insulations are negligible 5.42 Mt CO<sub>2</sub>-eq.

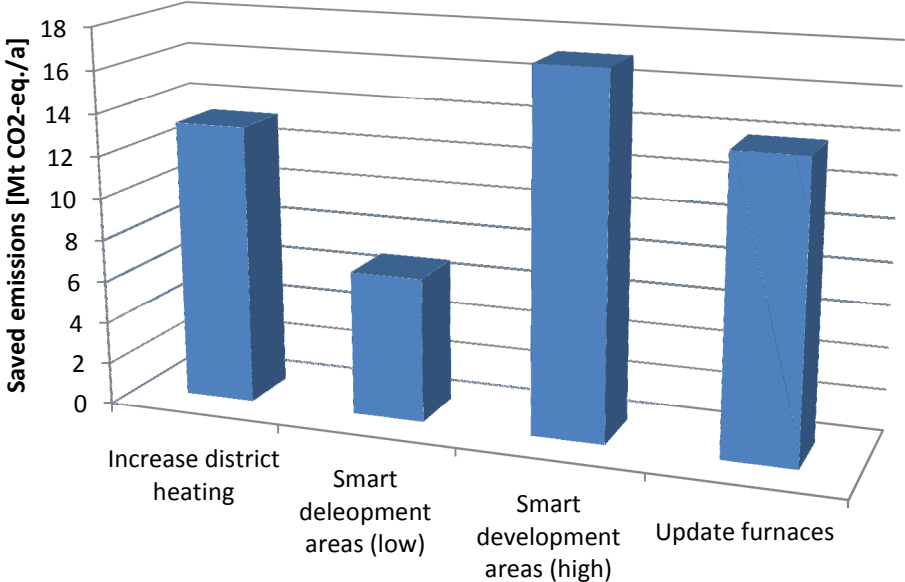
So the saving potential for the production of insulation material relates to the whole delivered energy demand for the complete German dwelling stock for 1-2 years.

Changing over the German building stock to a wood based results in a saving potential of 15.43 Mt CO<sub>2</sub>-eq./a and a storage capacity of 10 783.56 Mt CO<sub>2</sub> over the average lifetime of 90 years.

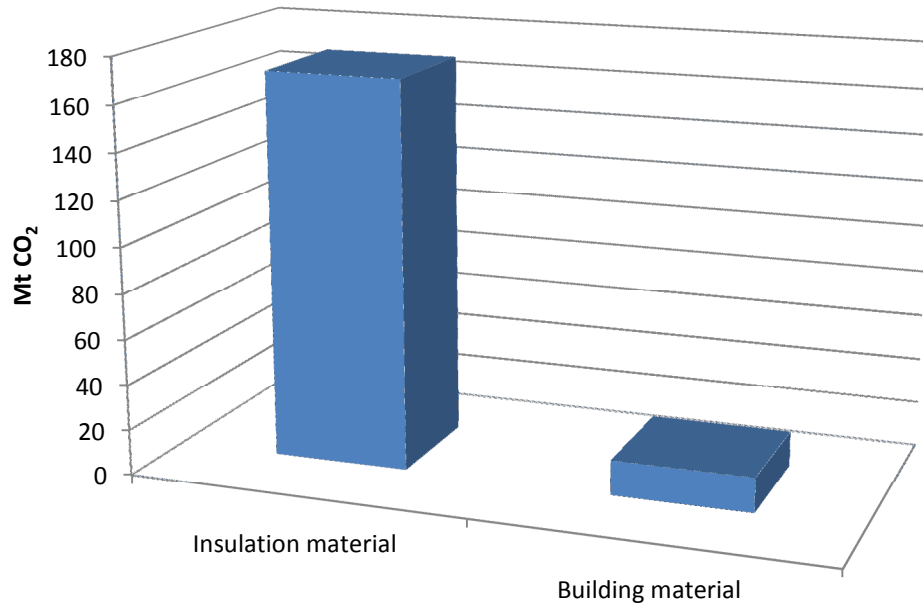
Of course those values are theoretical, as they also include high-rise buildings which can only be partially made of wood.

In comparison, the average costs for CO<sub>2</sub> storage range from 17 – 71 €/t CO<sub>2</sub> for conventional plants. ( Abellera, o.a., 2011) This would give the two storage capacities an average value of 7471.2 Mio. € and 678.92 Mio. € respectively, using a comparative pricing.

The following Figure 27 and Figure 28 give an overview of the measures introduced in that chapter and their saving and storage potentials.



**Figure 27: Annual emission saving potential**



**Figure 28: CO<sub>2</sub>-storage potential**

Due to statics and further construction reasons, e.g. fire safety, only a share of the storage potential is also technical possible.

## 4.6 Results of increased insulation

As introduced in the beginning of the chapter the different insulation standards require less net energy. This results in higher maximum shares in renewables, which corresponds to a reduced demand for non-renewables, and further reduced emissions as follows in Figure 29 and Figure 30.

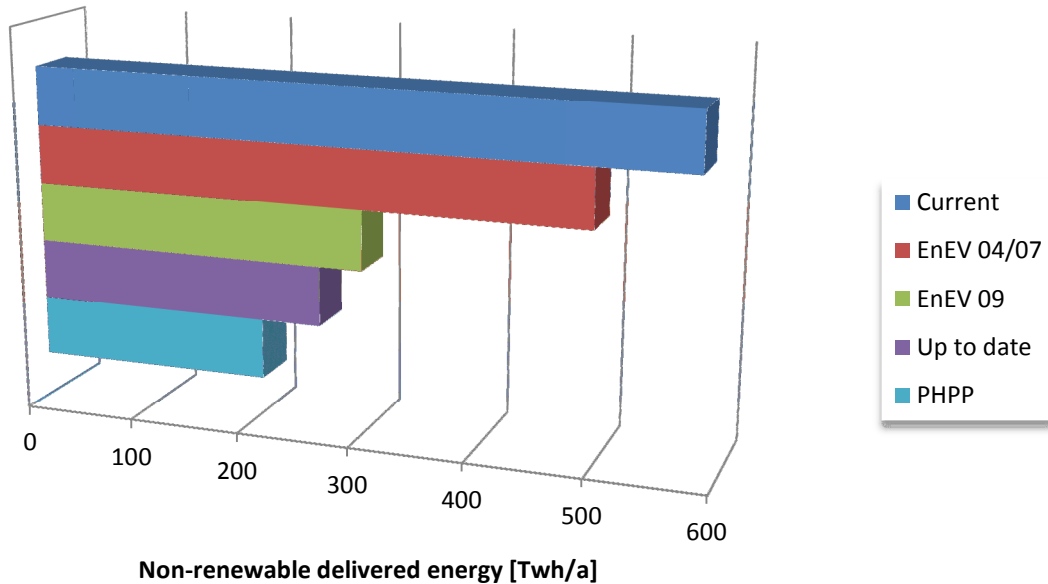


Figure 29: Demand for non-renewables delivered energy with different envelope standards

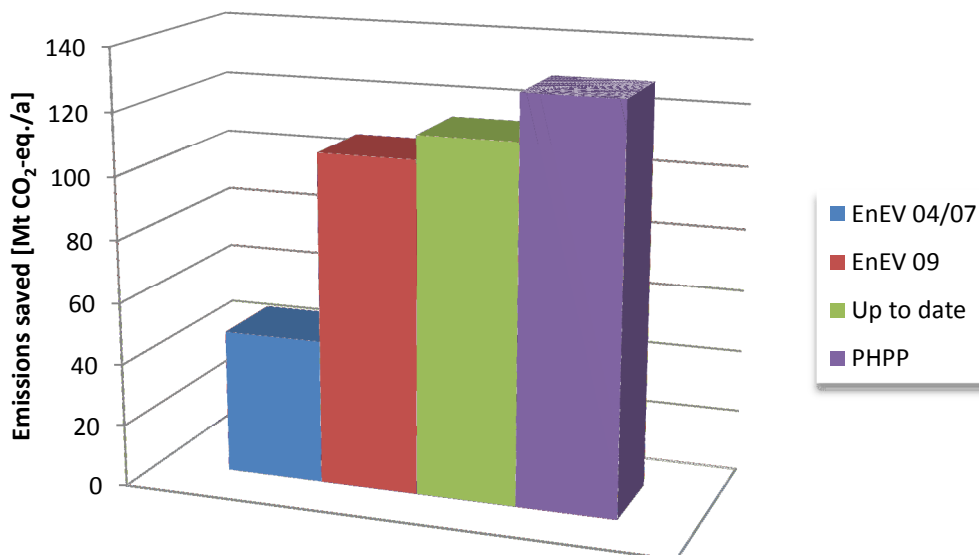


Figure 30: Emission saved by maximum renewables in the different insulation standards

## 5 Cost and sensitivity analysis

As mentioned before, the economic aspect is most crucial for the home owner, as it is the major thrive for the ‘unwilling ones’. So first of all the cost efficiency of several measures is investigated assuming the current costs. The economic profitability of all measures depends as well on the measure costs as on the energy prices, a change of the second follows in this chapter. Concluded is this part of the thesis by a sensitivity analysis to investigate the most sensitive parameters with respect to energy prices and interest rates.

### 5.1 Current economic output

The first scenario investigated is the one assuming the current prices to be constant over the lifetime of all measures. This scenario does not account for increasing fuel prices (see chapter 10.6) and is therefore not a realistic case. It thus must be seen as a reference for the further investigated energy price developments in the following chapter.

Figure 32 shows the results of the measures mentioned in the pathway project for an average building. It can be seen that not all the measures are cost efficient in the whole building stock.

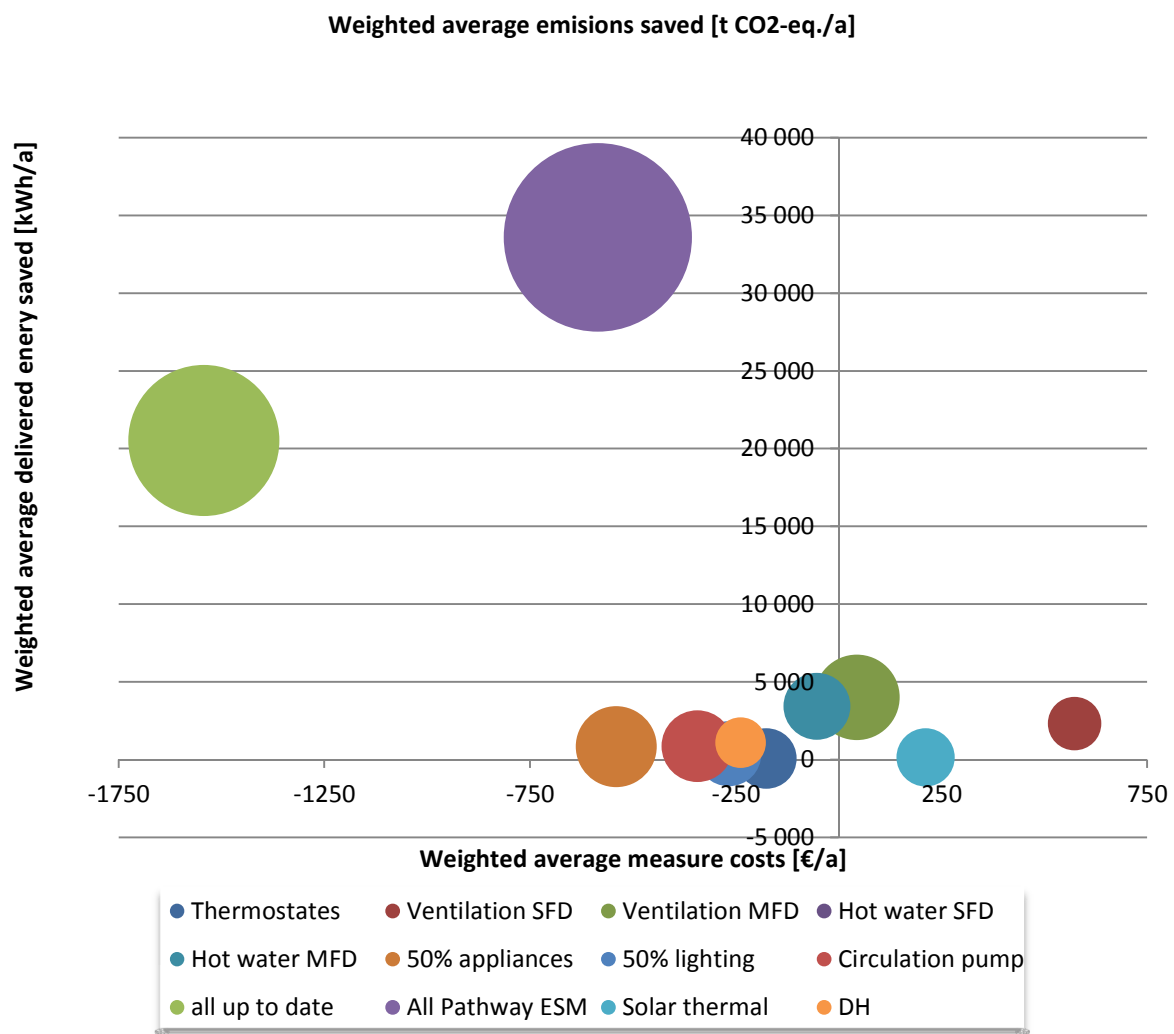


Figure 31: Saving potential for an average building

The following Figure 33 shows the savings potential for each measure, if only applied to the cost efficient building types. This represents the owners of the houses, as they are much more likely to invest in saving measures, which pay back over the time, or at least have no financial back draws. A detailed list of those measures and building types can be found in appendix 9.9.

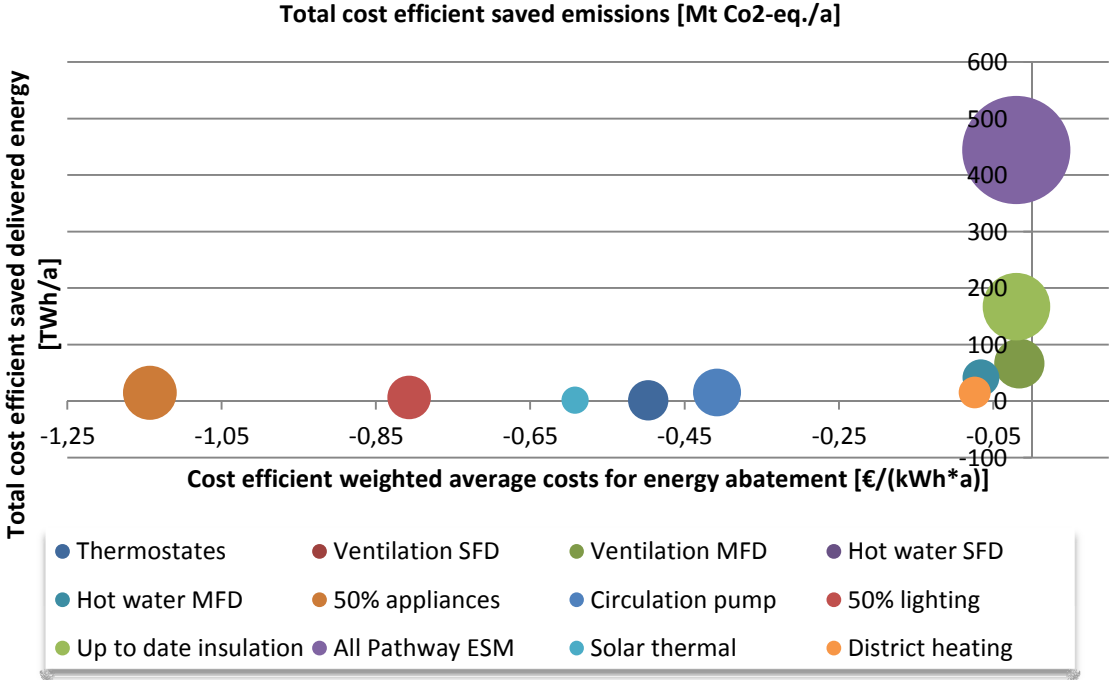


Figure 33: Result of cost efficient measures

Figure 34 and Figure 35 show the savings and cost efficient savings of the further investigated measures, including the accumulation of all measures investigated above.

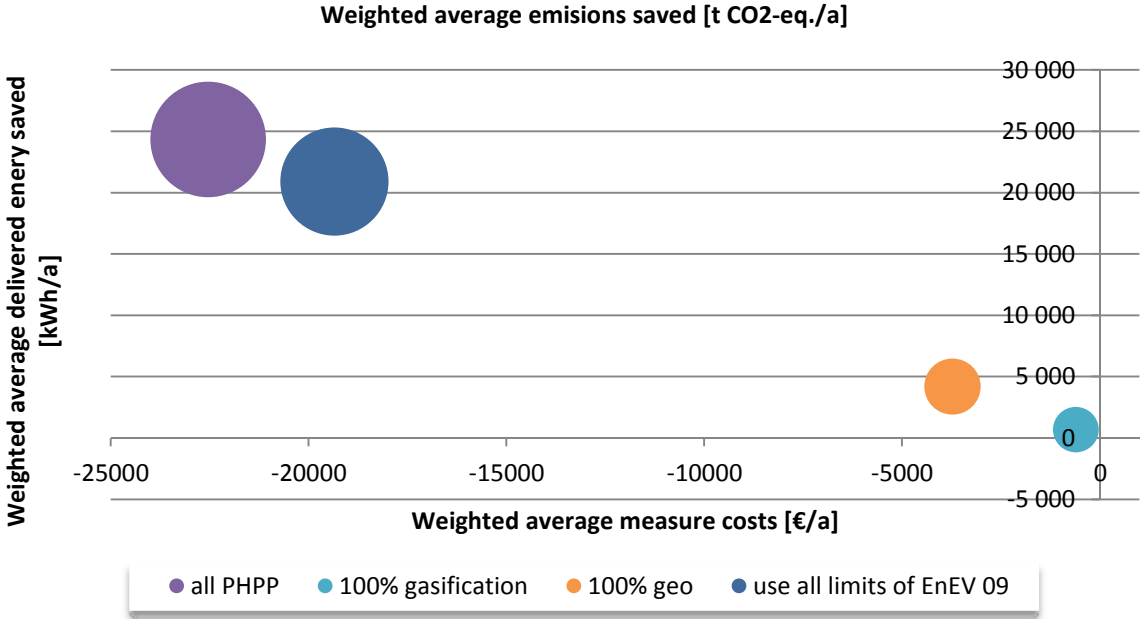


Figure 34: Savings by further measures

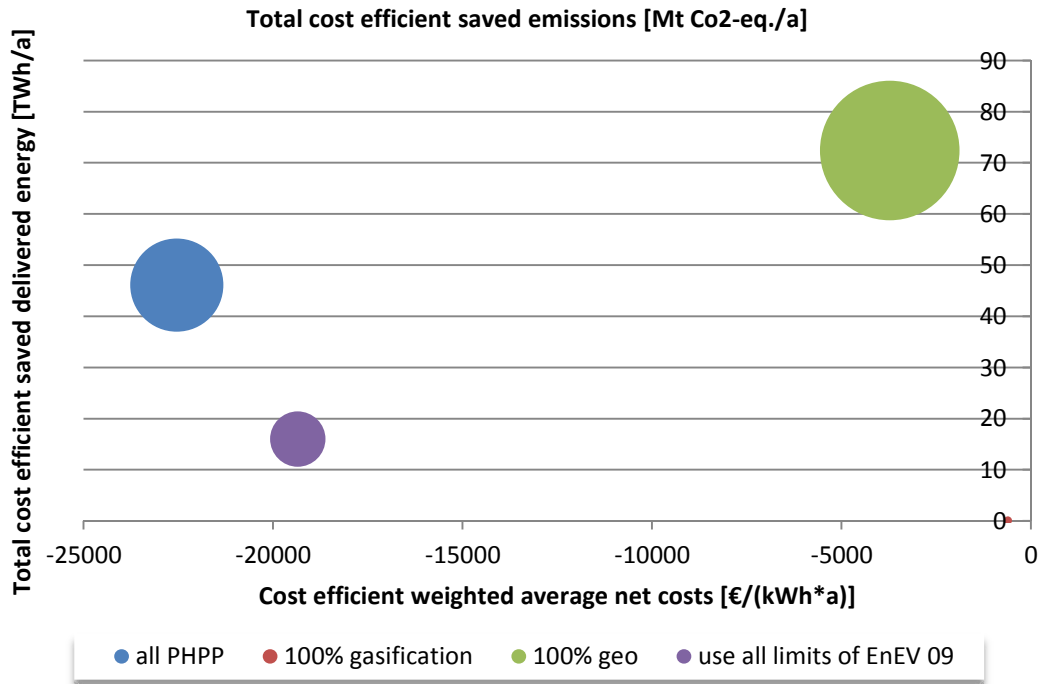


Figure 35: Cost efficient savings by further measures

These cost efficiencies do not include any subsidies. Thus the following Figure 36 gives an overview over the additional saving potential and the required subsidies. The subsidies in this case are the total costs for the measure reduced by the cost covered by fuel savings. All (positive) rebound and further effects are the bonus which makes it interesting to invest. In the diagram every dot stands for a building class and measure. A detailed list can be found in appendix 9.8.

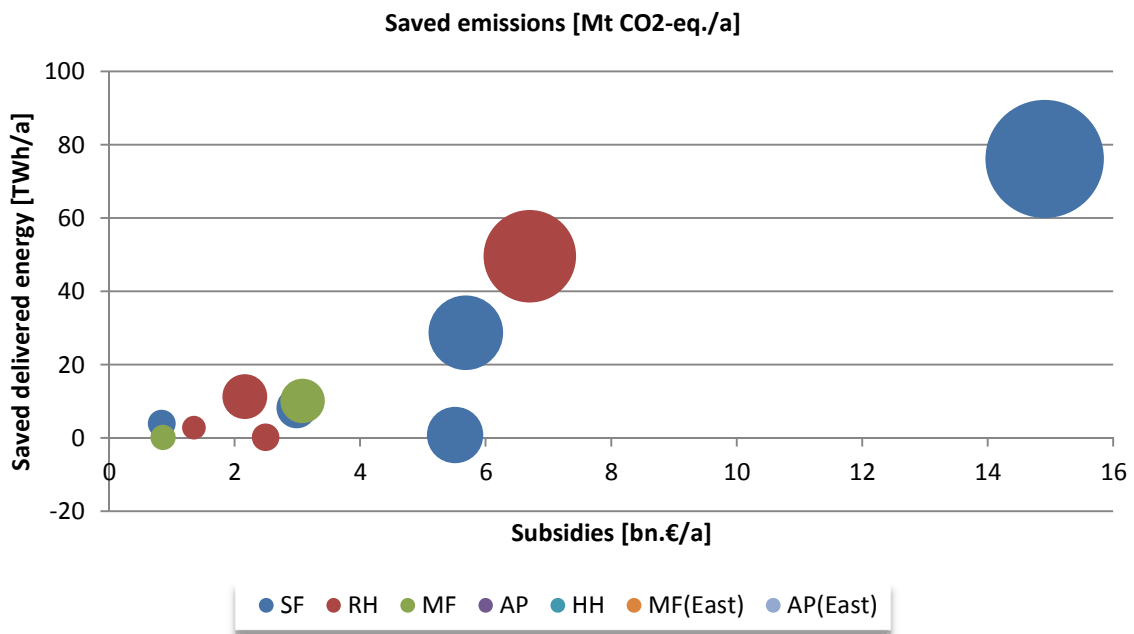


Figure 36: Additional savings potential and subsidies I

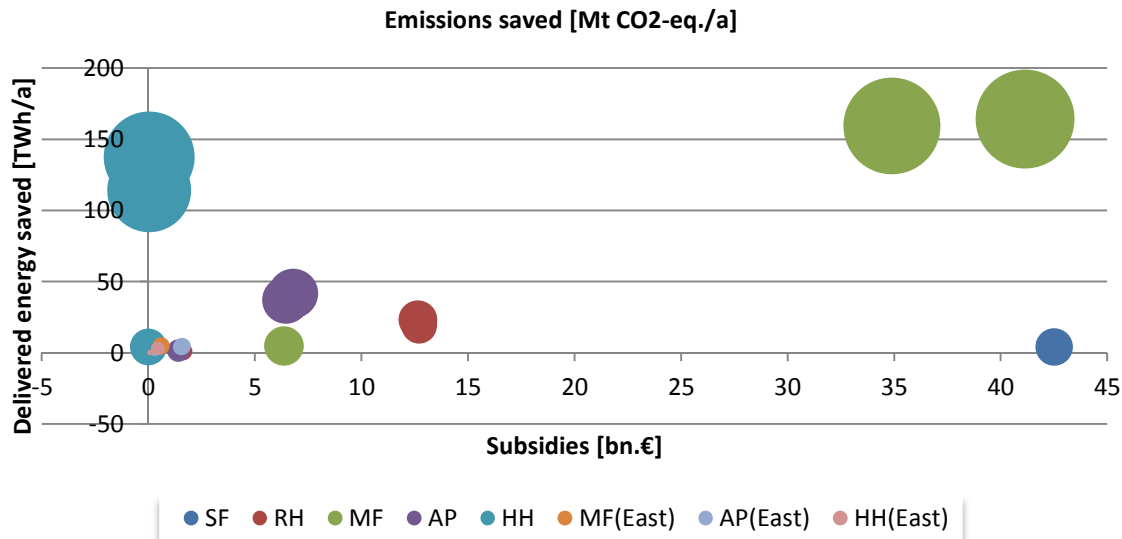


Figure 37: Additional saving potential and subsidies for the further measures

Figure 37<sup>21</sup> shows the required subsidies and the corresponding savings in delivered energy. As those subsidy volumes include taxation (19% as of May 2013) the total costs must be reduced by those taxes paid to the state treasury. Other effects, as reduced unemployment, business taxes etc. are not included in that calculation.

This shows that especially subsidy investments in bigger housing complexes return a big saving. Another advantage of investing in that group is a lower number of persons in charge and much more economic orientated decision makers.

The following Figure 39 shows the net cost per area and year in relation to the delivered energy demand of a building type after the renovation. Net costs in this case are the costs which accrue after accounting for the reduced energy costs. This means that building-measure combinations are favourable if they are located below the abscissa and to the left, the buildings require then fewer delivered energy and the renovation is cost efficient. It can furthermore be concluded that high interest rates reduce the cost efficiency of measures and thus increase the required subsidies. The interest rate of 1% is of special interest for the house owner, as this rate is granted to such from the *KfW* for energy renovations. (*KfW*) It can be seen that the majority of buildings can be brought to or below the '7 Liter House' standard<sup>22</sup>, which means reducing the demand by more than half, see Figure 48. In comparison the current average value is 203 kWh/(m<sup>2</sup>\*a).<sup>23</sup>

<sup>21</sup> Figure 37 does not display PHPP and EnEV09 renovations in SF for better visibility.

<sup>22</sup> '7 Liter Haus' refers to the demand of 7 litres of oil to heat 1 m<sup>2</sup> for 1 year for a SFD.

<sup>23</sup> From Wanjani and Bauer and chapter 4.2.1.s

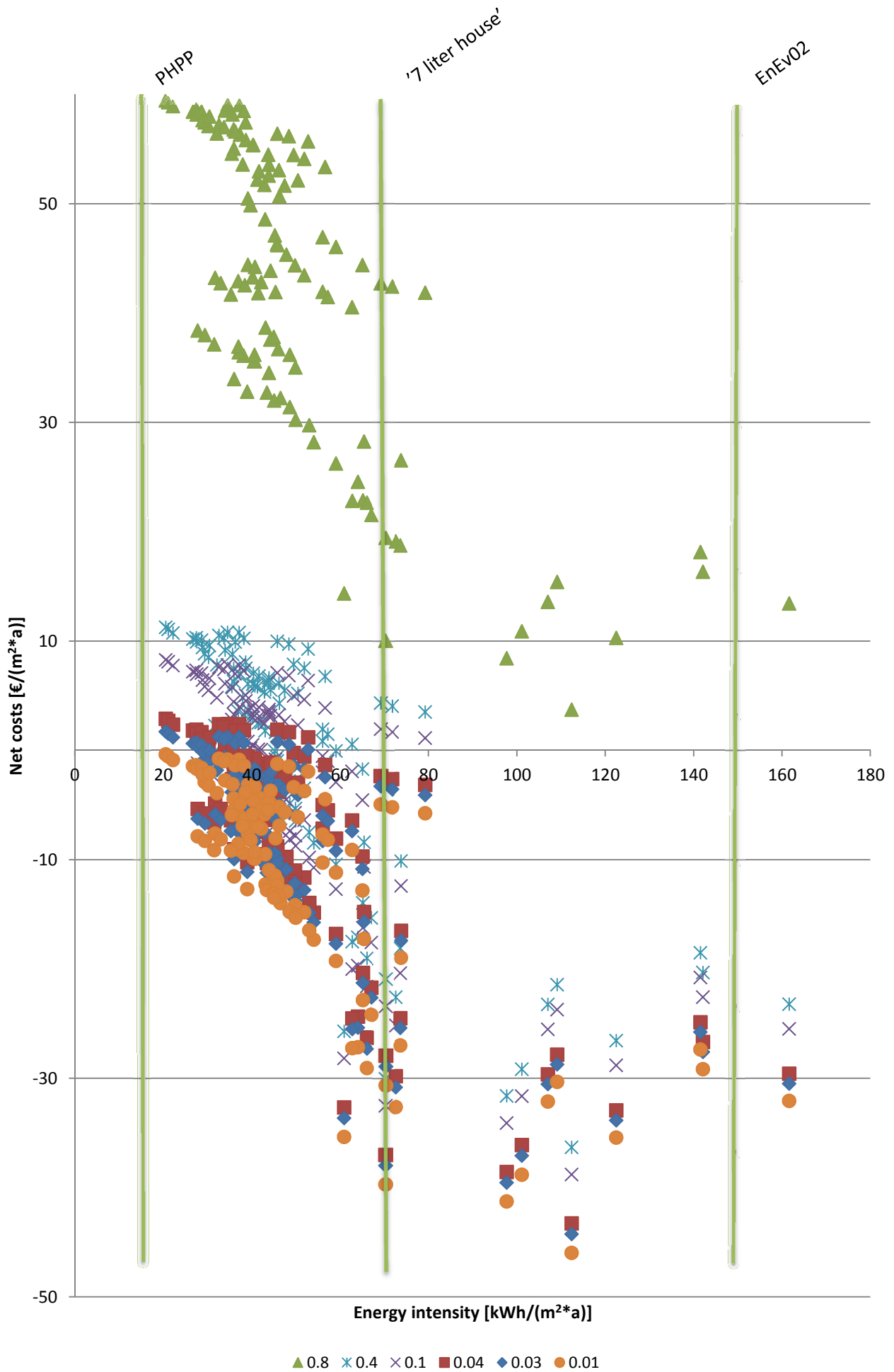


Figure 39: Net costs over intensity of the german building stock (all ESM)

Using the same data, but for one interest rate (0.03) the following Figure 40 and Figure 40 gives an overview which measures are most cost efficient to implement in the single family dwelling building types (SFD) and multifamily dwellings (MFD) respectively. The diagrams show that the output of the majority of the measures can be approximated as a quadratic function and thus have a total minimum. For the MFDs this minimum would have a negative energy demand. It is also visible that the bigger the building is, in terms of area, the more cost efficient is an energy optimal renovation, nearly linear.

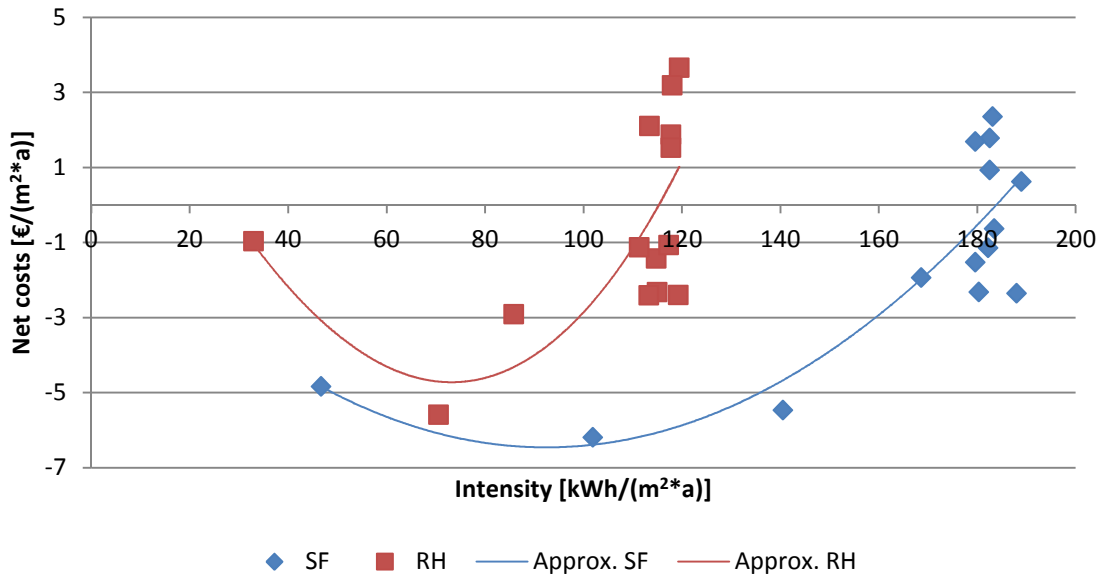


Figure 40: Net costs - intensity diagram for SFDs

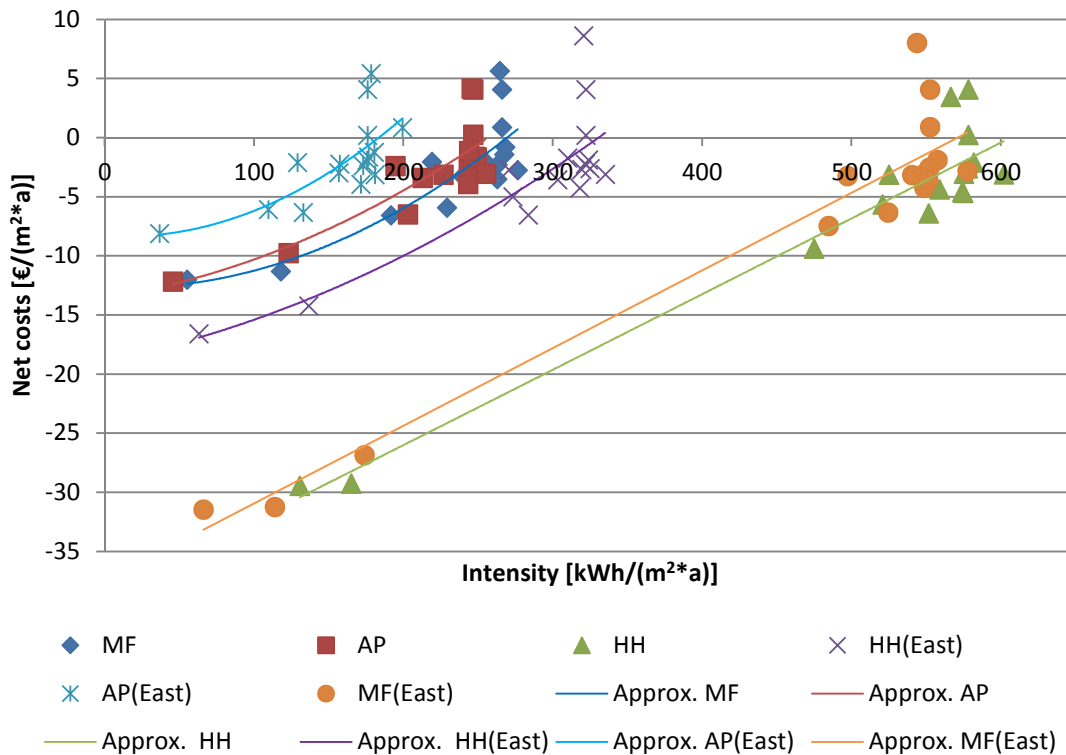


Figure 41: Net costs - intensity diagram for MFD

The above measures apply all the insulation measures at once and do not investigate their individual cost efficiency. The following Figure 42 closes that gap and shows their individual and aggregated savings. It can be seen that the insulation of the floor is the only cost efficient measure, but has also rather small savings. The least efficient one is the renewing of the windows, which has the poorest cost efficiency and also the lowest savings in both, energy and emissions. The synergies by combining it with other measures might reduce those costs a little, as 70% of the costs are labour costs. (Hall)

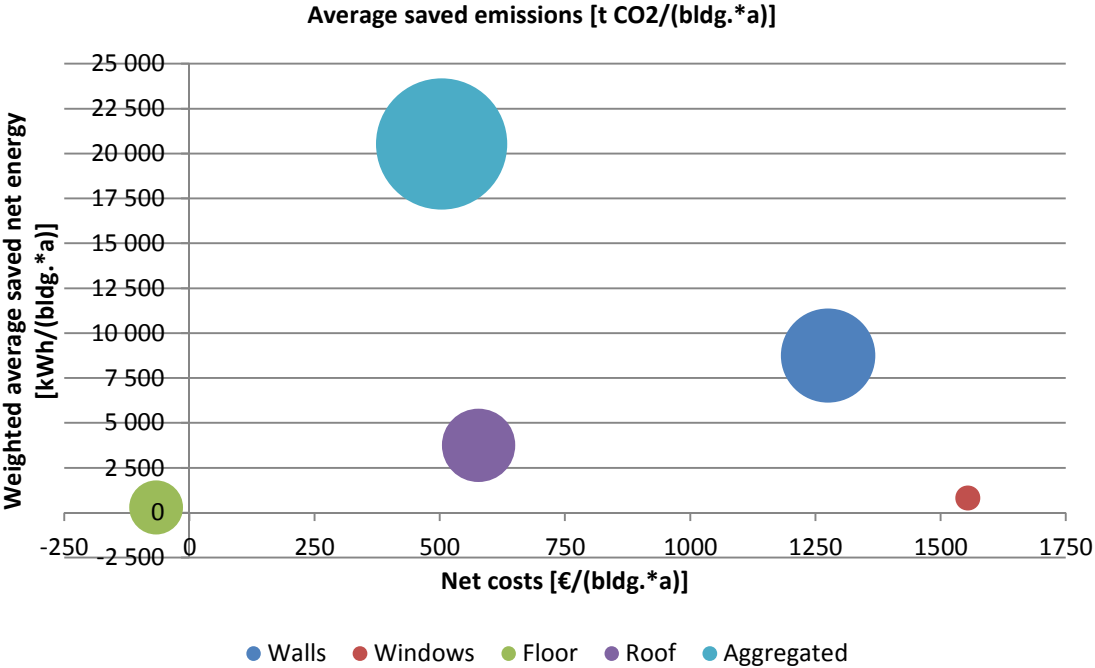


Figure 42: Comparison of the different individual insulation measures

## 5.2 Changing energy prices

As mentioned above in the current model the energy prices are fixed. According to the energy price development this is not a very plausible scenario. Thus a price change from -20% to +25% is investigated. The prices are consumer prices, so including taxes, for this reason also negative and rather high increases are investigated. This also represents additional taxes, e.g. with respect to heating value or for emissions. The following Figure 43 shows the price sensitivity of the savings of the measures grouped in the pathway project.

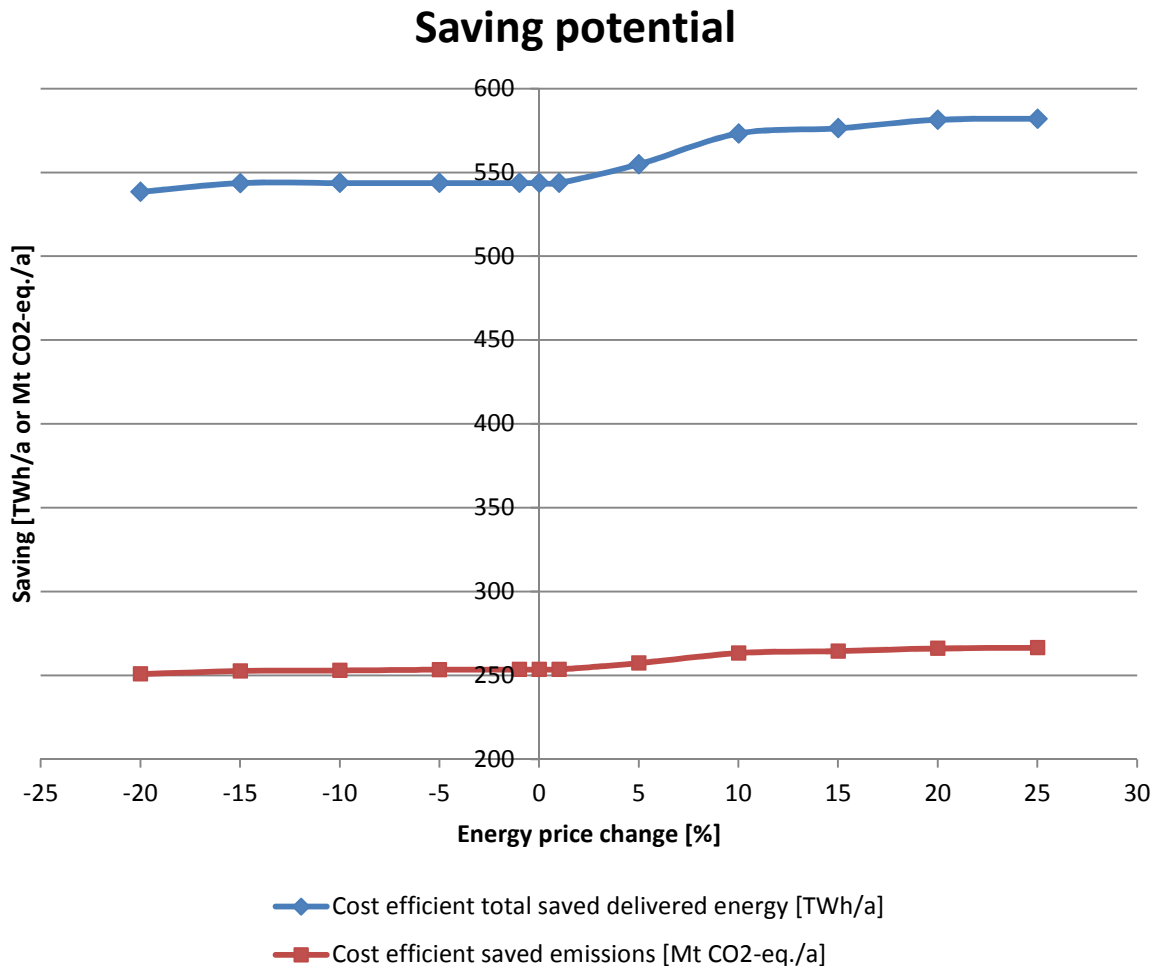


Figure 43: Price sensitivity of all PW measures

From Figure 43 it can be seen that more than 10% increase does not result in a significant higher cost efficient saving potential. As the price increase is very likely, keeping the German energy strategy in mind, this potential should be accounted for, as the measures last for 40 years.

### 5.3. Sensitivity analysis

The sensitivity analysis indicates how the cost efficiency can be manipulated most easily. And which parameters are hardly to influence at all by the energy price. The following Table 21 shows the different sensitivity coefficients for the different outputs. More detailed calculations and parameters can be found in chapter 9.7.

**Table 21: Sensitivity coefficients**

<b>Output</b>	<b><math>S_{i,j}</math></b>
<b>WAvg.EAC</b>	0
<b>WAvg.S</b>	3.0810
<b>WAvg.SNetE</b>	0
<b>WAvg.EmS</b>	0
<b>TotEmS</b>	0
<b>TotSDeIE</b>	0
<b>WAvg.CE</b>	-3.6011
<b>WAvg.AC</b>	-1.9910
<b>Cef TotSDeIE</b>	0
<b>Cef TotEmS</b>	0.04277
<b>Cef WAvg.CE</b>	3.5597
<b>Cef WAvg.AC</b>	2.7115

The outputs referring to cost efficiency are most easy to influence. This can be interpreted as several measure-.building combinations, which are close to a financial profitability.

## 6 Discussion

In terms of energy demand and emissions all measures investigated can be advised, as they all reduce the demand and emissions, except from some newer buildings.

A more detailed discussion the deviation will not be given, as the calculations were done with MatLab and rounded heavily (e.g. from kg to Mt). It is assumed that MatLab provides sufficient accuracy.

### 6.1 Comparison of different measures with literature

The following Table 22 gives an overview of the savings estimated for the different ESMs and compares them to other research found in literature. If not defined other, the characteristics of the parts are brought to an up to date standard. As this research introduces several measures the first time to a whole building stock, not for all a reference could be found.

**Table 22: Comparison of the different measures**

Measure	Del. energy saved [TWh/a]		Emissions saved [Mt CO <sub>2</sub> -eq./a]		Reference source
	ECCABS model	Reference	ECCABS model	Reference	
<b>Reduce T<sub>in</sub></b> <sup>24</sup>	55.26	41.58	28.34	12.64 <sup>25</sup>	Dena, Stiftung Warentest
<b>Ventilation</b>	89.1+63.85	60	39.48+33.21	20	(Kaup, 2009) <sup>26</sup>
<b>Walls + roof</b>	146+73.66	-	53.49+33	69 <sup>27</sup>	(Beer, o.a., 2009)
<b>Windows</b> <sup>28</sup>	36.67	39.36	26.38	8.58 <sup>29</sup>	(Hermes, 2006)

<sup>24</sup> Reduction by 1°C

<sup>25</sup> Assuming 0.466 Mt CO<sub>2</sub>-eq./TWh emissions

<sup>26</sup> Study includes further technical restrictions (HVAC) and assumes unwillingness of consumers (to avoid high investment costs for small buildings).

<sup>27</sup> Only economic savings considered.

<sup>28</sup> Average U value of 0.8 W/m<sup>2</sup>

<sup>29</sup> The study only considers gas and oil as fuels, and assumes dwellings for 4 persons.

<b>Appliances</b>	9.06	8.2	29.17	6.67 <sup>25</sup>	(VDE, 2008)
<b>Circulation pumps</b>	9.71	3.9 (el.) + 6.6 (heat)	22.97	22.5 (el.) + 1.52 (heat) <sup>30</sup>	(Wohlauf, et al., 2005)
<b>Insulation to up to date standard</b>	318	304	103.99	63	TABULA
<b>Insulation to PHPP standard</b>	390	512	120.34	100	TABULA

The detailed achieved results will also depend on a range of non-technical aspects, as rebound effects and a general shift to a greener lifestyle. Here it must be argued that a reduced energy bill might e.g. lead to a reduced awareness of the energy demand.

The total sum for the subsidies introduced in chapter 5.1 is 44.85 bn. €. The major German subsidies for building efficiency have a volume of 72.35 bn. €, see Table 23 below. The much smaller savings are due to the fact that the savings are calculated against a renovation to an EnEV09 standard dwelling.

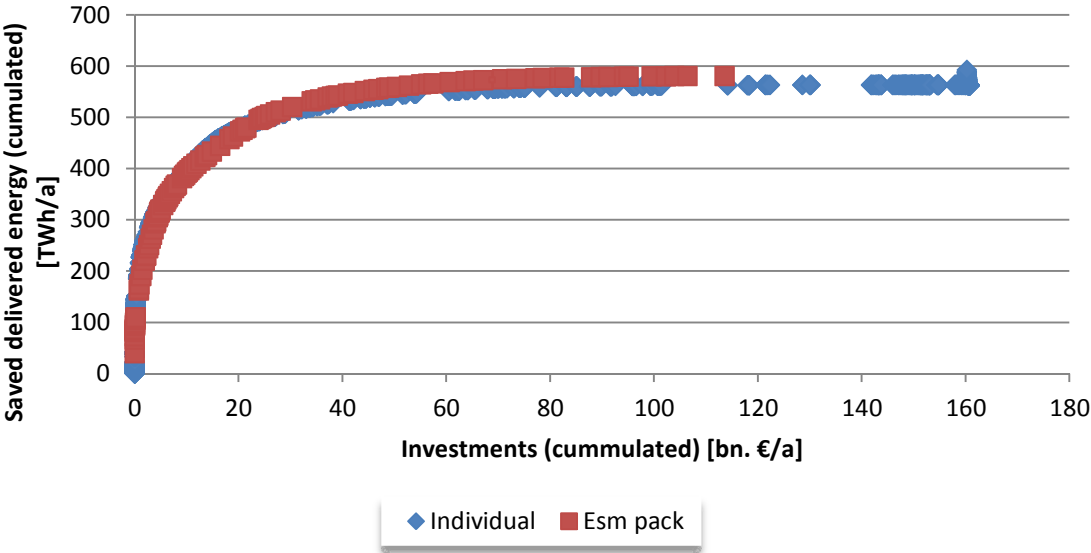
**Table 23: German building efficiency subsidy programs (2005-2011)**

<b>Program</b>	<b>Subsidies [bn.€]</b>	<b>Emissions saved [Mt CO<sub>2</sub>-eq./a]</b>	<b>Delivered energy saved [TWh/a]</b>
<i>Effizientes Bauen 2011</i>	14.5	0.085	0.37
<i>Effizientes Sanieren 2011</i>	3.85	4.2	1.68
<i>Effizientes Bauen 2006-2010</i>	47	0.41	1.34
<i>Effizientes Sanieren 2005-2011</i>	7	3.7	2.45
<b>Total</b>	72.35	8.4	5.84

<sup>30</sup> Assuming the emissions for electricity in 2009 (see 9.2) and 0.466 Mt CO<sub>2</sub>-eq./TWh<sub>heat</sub> (see 4.2.1).

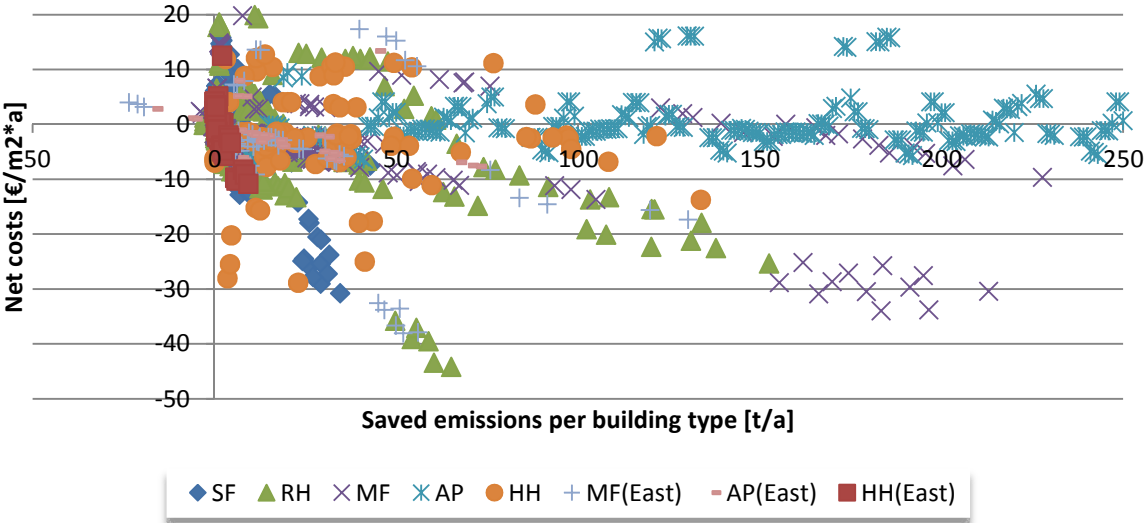
<b>PW measures</b>	44.85 /a	40.04	90.18
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To save as much energy and emissions as possible specific buildings need to be addressed, based on the characteristics (Age, building type and climate zone) individually. This can be done by listing all buildings sorted by the delivered energy saved per bn. € invested. The following Figure 44 accumulates this list from the top. It can be seen that 19 bn.€/a in investment save 464 TWh/a, which means that ~17% of the maximum investment saves 80% of the total technical saving potential.



**Figure 44: Cumulated investments and delivered energy saved**

Where as Figure 44 accumulates the costs and delivered energy over the whole building stock Figure 45 plots the saved emissions and the corresponding costs for each building type. It can be seen that the most saving potential per building can be found in high rise buildings (HH), apartment buildings (AP) and high rise buildings East (HH(East)). This is also due to the higher heated floor area of such buildings (per building), but the majority of the measures are per building, not per heat floor area. This potential per building type is also favourable as subsidies and legislation are with respect to the building type.



**Figure 45: Emission saving potential per building**

An investigation by the age of the buildings shows a similar result as already drawn by Wanjani and Bauer, namely that low energy costs and rare building materials (in Eastern Germany) in the '60s and '70s result in bad energy performances, see Figure 46. Thus such buildings should be addressed first. As the majority of such renovations is cost efficient a subsidy is not necessary, rather according regulations. Extremely good performance have the buildings before 1918, which are only partly displayed due to better visibility.

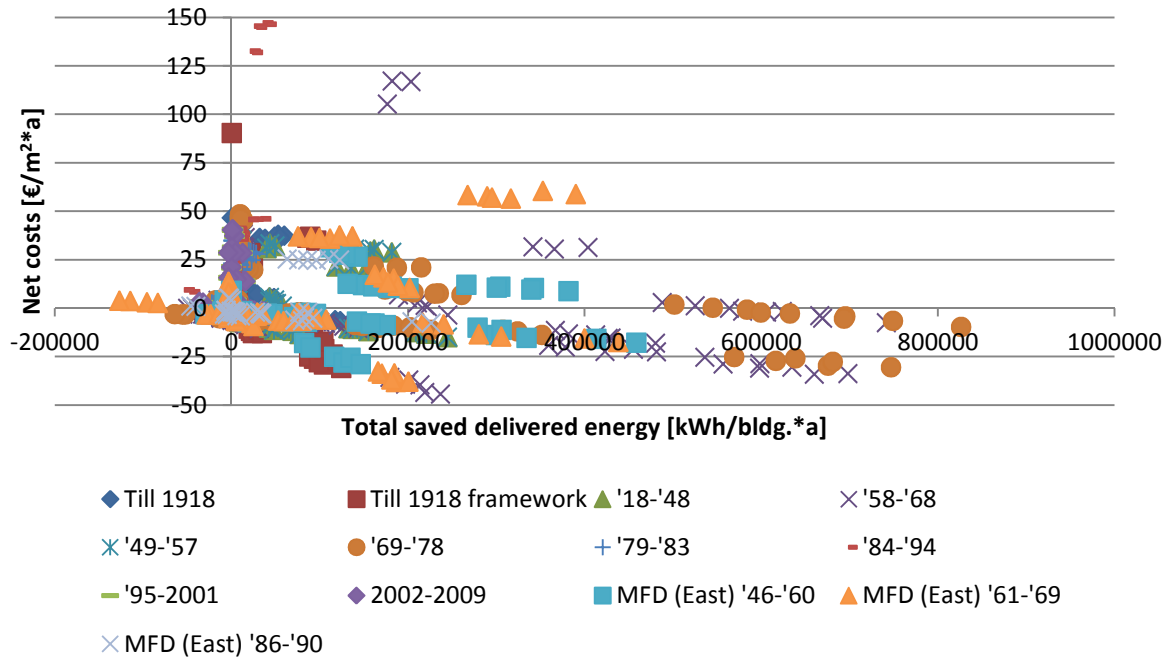


Figure 46: Energy saving potential per building by age

Similar results can be found by the emission saving potential per heat floor area, see Figure 47.

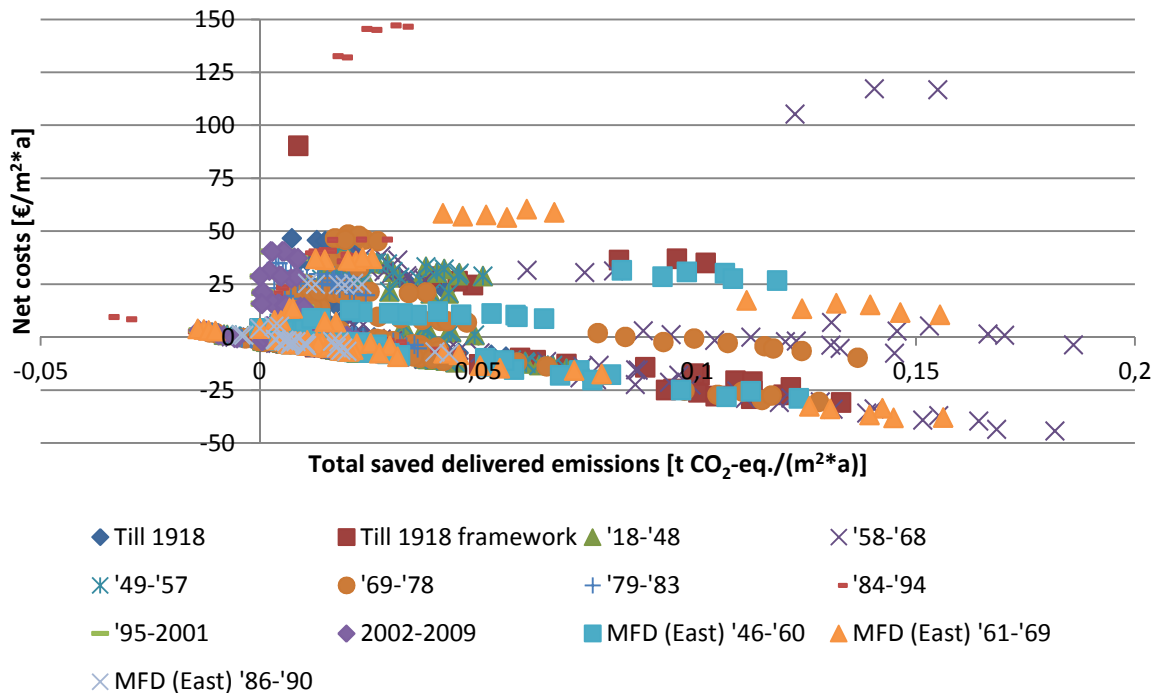


Figure 47: Emission saving potential per heat floor area and by building age

The packages of two or more measures offer the biggest saving potential. As stated in chapter 4.3.5 the sum of all delivered energy saved per individual measures is smaller than the savings applying all measures at once. This is due to the fact that different measures improve the delivered energy demand differently, some reduce the net energy demand and some the delivered energy demand directly. Reducing only the net energy demand (e.g. insulation) the ratio between net and delivered energy is the same, so only a slightly milder decrease in delivered energy demand. By only increasing the conversion efficiency (e.g. new furnace) less delivered energy is required to delivered the same net energy. Applying both measures reduces the delivered energy demand more, as the conversion from delivered to net energy is at a fixed ratio.

## **6.2 Limitations of the results**

One of the most obvious limitations is the general approach of the model. The model uses average values and these results are not applicable for every building.

In addition other restrictions, e.g. heritage status of the building, financial status of the owner etc. are not considered in the model, even though they have a major influence on the savings achievable in practice.

The mentioned limitations due to heritage status of buildings have been assessed and estimated to be about 48.61 TWh (175 PJ), which is equal to about 8.7% of the heating demand in German dwellings in 2011. (Jochum, et al., 2012) This amount of heat could be saved every year using technical measures, but to preserve the look and status of the building it is not done. It must therefore be subtracted from the energy saving potential, assuming that those limitations are the same for any kind of energy make over.

Besides the limitation on the housing sector, this thesis is also limited by the fact that statistics where used. So to apply the results given in this thesis one needs to check for each case in detail as not all assumptions might apply to the specific case, e.g. possibility for geothermal energy.

Furthermore are the outcomes of that work based on the data put in. Especially the building stock data, efficiencies and prices have a high influence or might be subject to rapid change. While the cost output is also very much depending on the interest rate.

## 6.3 Recommendations

*'If you can not measure it, you can not improve it.'*

This quote by Lord Calvin is also very true for the energy efficiency of the building. Only if one can (and has) measured his energy demand (and compared it), it is possible to take actions.

The energy performance certificates (*Energieausweis*), see Figure 48, puts the actual (fossil) energy demand of a building in relation to the size and enables to compare different buildings with respect to their energy demand. Due to the low rate of (energy) renovations and constantly increasing energy requirements similar rated buildings might have similar constructions and thus similar optimal ways to reduce energy demand. From the distributions of those energy labels two major strategies are thinkable and should be applied simultaneously:

- 1) Start with the highest demand, as they promise the highest saving. Those savings might be limited, as those buildings are most likely also subject to restrictions in terms of aesthetic appeal or other factors discussed earlier.
- 2) Start with the biggest share of buildings. Those buildings have a lower saving potential per building, but in sum the total saving potential is big.

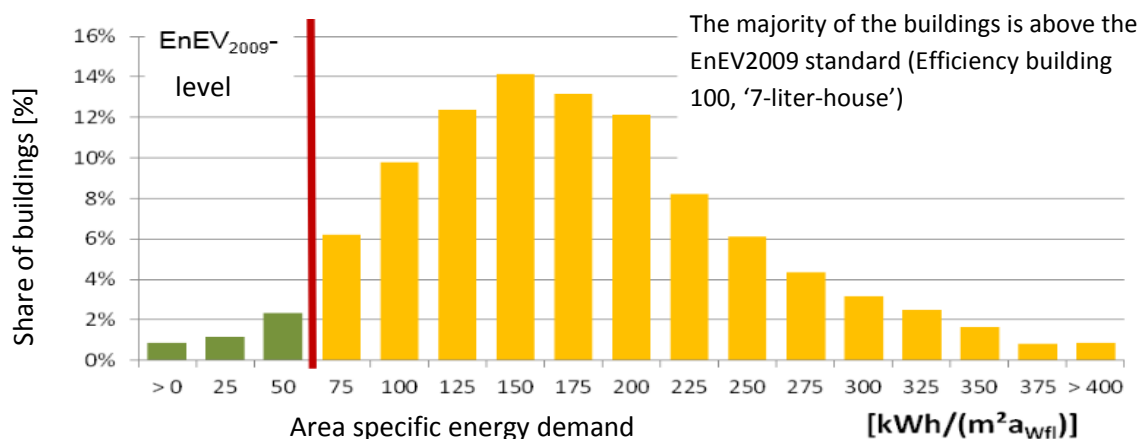


Figure 48: Area specific energy demand

Another recommendation that can be given is referring to the order in which an energy home improvement should be performed. As mentioned earlier the availability of the different renewable energy sources vary from building to building. This should be the first step to investigate, as this energy is nearly free and renewable. The following step must be a full planning for the building (or even bigger units like quarters or villages), as certain measures influence others (see Figure 3). Such planning must also include the future use of the building as it influences the planning. The planning of the used energy sources should follow the availability and emission intensity (first low emission and high (local) availability). From an economic point of view a home improvement might be better done in a step wise approach,

rather than in one big step. From an ecological approach the opposite is true, as especially high efficient measures pay back fast. In terms of order the envelope must be planned first, as it influences all other measures but is not influenced by any other. Then the furnace, including all alternative heat sources, as it depends on the envelope. Lastly the time should be planned. Here, as mentioned before, the earlier the better. But synergies with ‘optical’ renovations should be used to decrease costs and discomfort.

Another recommendation, keeping in mind the time between (energy) renovations in Germany, is to stricken the energy requirements for newly build dwellings and other buildings. As mentioned above the higher financial investments, which are one major reason for an energy non optimal renovation, should be partly or at least more funded by the state. If not so called lock in situations appear. This means that the saving potential is technically there, but can not be achieved due to financial restrictions. Furthermore the owner is most likely not willing to do another major renovation within some years, even though it is cost efficient over the whole lifetime of the measures applied. Assuming that all buildings will reach a close to PHPP standard at some time, subsidies can also be seen as a way to jump one or more steps towards the final state.

To further improve the average efficiency of furnaces a program similar to the car scrappage scheme could be of great use. The scheme paid owner of old cars 2500 €, if they scrapped their cars and bought a new one, not older than one year. In addition a strict ban on selling and reselling old furnaces might be of great use.

## 7 Conclusion and further research

From the individual measures investigated the introduction of ventilation in multifamily dwellings has the biggest saving potential (25.38 Mt CO<sub>2</sub>-eq./a and 66.37 TWh/a). Whereas the reduction in demand for lighting is the most cost efficient one (-0.756 €/kWh\*a), this measure saves 19.16 Mt CO<sub>2</sub>-equivalent and 6.48 TWh per year. Furthermore, these measures are not affected by the heritage status limitation. The measures concerning the ventilation and the hot water production of single family dwellings (SFD) can not be introduced cost efficient in the whole building stock, only to a certain share.

The average heating demand with respect to the year of construction demands for much stricter rules, e.g. on heat transfer and air tightness, for existing houses. The current regulations mostly only apply to newly built houses or sold ones, but these account only for a marginal share of all the houses. Furthermore a large number of exceptions in the set of rules reduces the achieved saving dramatically.

The focus in terms of measures must be drawn to the electric appliances. Those measures, already in place, have major benefits in all building classes, and are by far the most cost efficient ones, as stated above. It can be seen that the cost efficiency and saving potential of all other measures depend on the building type.

An investigation by building type shows that the most potential, neglecting the electric update, is found in the multifamily dwellings and apartment houses. Also geothermal systems can be introduced in the whole building stock cost efficiently.

Furthermore all building types exclusive to East Germany can be renovated cost efficiently without any subsidies.

The ESM package, including all measures introduced in the pathway project, has a saving potential of 158 Mt CO<sub>2</sub>-eq./a, about half of the current emissions and 46% of the delivered energy (580 TWh/a). The subsidies for the 56.22 Mt CO<sub>2</sub>-eq./a (187.88 TWh/a), which can not be saved cost efficient is estimated to 30.07 bn.€/a or 0.53 €/kg CO<sub>2</sub>-eq..

The average period between two renovations is about 45 years in Germany. This means that all buildings which are renovated after 2005 are not expected to be renovated before 2050. To achieve the maximal effect of the renovations, the buildings must be brought to the highest energy standard with respect to technical limitations and fiscal aspects. This is also the only way to prevent the locked-in effect, where the building stock can't be renovated cost efficient as the latest renovation is just some years ago.

A general advice on specific measures for all buildings is not resulting in the most efficient building stock. Or in other words: not every building or building class, benefits from every measure, some even consume more energy than before. In fact an investigation for each house or small group of very similar houses needs to be done, to find the optimal solution.

The sensitivity analysis emphasises to also invest in measures, which are cost efficient with a 10% increase in energy prices, as the saving price curve reaches a node then. The resulting cost efficient measures save additional 10 Mt CO<sub>2</sub>-eq./a and corresponding 30 TWh/a.

The net cost – intensity diagram shows that the price range for buildings is about 40 €/(m<sup>2</sup>\*a). Depending on the interest rate the corridor moves. At the currently subsidised rate of 1% the package including all measures can be applied to the whole building stock cost efficiently.

During the thesis a list of further fields of investigations has grown. This may be investigated in further works to complete and extend this thesis.

- More detailed maps for renewables, instead of an equal distribution, to allow a more detailed resolution for buildings
- Introduce a database for the results to allow easier data analysis and the ability to answer related questions by (future) house owners
- Include primary energy into the analysis
- Distinguish between renewable and non-renewable energy in the output
- Include SO<sub>2</sub>-equivalent and further environmental factor into the code
- Include further renewables into the code, to allow easier transformation
- More detailed investigation of the energy and emission saving potential and the emissions storage potential of building materials
- Water balance (production and demand) over the day for reusing water in buildings

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## 9 Appendixes

### 9.1 Energy standards for dwellings in Germany (and some reference values)

Standard	Max. heating demand [kWh / m <sup>2</sup> *a]	Max. Primary energy demand [kWh / m <sup>2</sup> *a]	Max. heat losses due to transmission [kWh / m <sup>2</sup> *a]
Av. Non-renovated house, built '60s –'80s	300		
WSVO 77	250		
Est. av. 2012 (Kohler, 2012)	175		
WSVO 82	150		
WSVO 95	100		
Low-energy house (EnEV02)	70		
KfW-60-Haus (EnEV04)		60	
KfW-40-Haus (EnEV04)		40	
KfW-Effizienzhaus 70 (EnEV07)		60	70 % allowed by <a href="#">EnEV 2007</a>
KfW-Effizienzhaus 55 (EnEV07)		40	55 % allowed by EnEV 2007
KfW-Effizienzhaus 85 (EnEV09)	55	~ 50	100 % allowed by EnEV 2009
KfW-Effizienzhaus 70 (EnEV09)	45	~ 40	85 % H <sub>T,Ref</sub> allowed by EnEV 2009
KfW-Effizienzhaus 55 (EnEV09)	35	~ 30	70 % H <sub>T,Ref</sub> allowed by EnEV 2009
KfW-Effizienzhaus 40 (EnEV09)		~ 24	55 % H <sub>T,Ref</sub> allowed by EnEV 2009
Passive house (PHPP)	15	120 <sup>31</sup>	
Effizienzhaus Plus <sup>32</sup>		0	

<sup>31</sup> Includes heating, warm water, air conditioning, cooling and electricity for appliances.

<sup>32</sup> Max. final energy demand  $\leq 0$  kWh / a m<sup>2</sup>

## 9.2 Greenhouse gas emissions of different fuels and their efficiencies

For the simulations the following emissions (carbon intensity) and efficiencies have been used, unless stated different.

### Fossil

Fuel	Gas	Oil	District heating	Electricity	Coal	Others
Emissions [g CO <sub>2</sub> -eq. / kWh final energy]	245	313.5	251	579	330	290
Furnace efficiency [%]	90	85	98	29 and 40 (heat pumps) 98 (direct and electric boilers)	1	85

### Renewable

Fuel	Heat pumps	Biomass / waste	Solar
Emissions [g CO <sub>2</sub> -eq. / kWh final energy]	0	91.4	0
Furnace efficiency [%]	29 and 40	70 (40 open fire)	1

### 9.3 Properties of different insulation materials

The different types of materials, their (primary) energy demand, their costs for the same insulation (same U value) and their availability are listed in the Table 24 below. Another column indicates if the basis material is renewable (R), fossil (F) or a waste product (W).

Table 24: Characteristics of different insulation materials (MHS)

Material	Availability (high / medium / low)	Primary energy consumption [kWh/m <sup>2</sup> ]	Costs [€/m <sup>2</sup> ]	Thickness [cm]	Type (renewable / fossil / waste)
		For U = 0,2 W/m <sup>2</sup> *K			
Hemp	M	14 - 16	25	20	R
Flax	M	X	25	22.5	R
Planning chips	H	13.75	18 - 23	27.5	W
Wood fibre (loose)	H	135 – 176.625	17 - 23	22.5	W
Wood fibre panels	H	120 – 235.5	40	20 - 30	W
Wood-wool slab	H	15.75	87	45	W
Calcium silicate panel	H	X	25	5	W
Coco fibre	H	19 – 23.75	44	22.5 - 25	R <sup>33</sup>
Cork (Granulate, baked, panels)	L	18 – 22.5 7 – 16.25 72 - 90	25	20 - 25	R
Mineral fibre	H	9 - 147	9 - 21	17.5 - 25	W / R
Expanding pearlite	H	18 – 105.75	20 - 45	22.5 - 30	R

<sup>33</sup> but is grown in monocultures and needs a long transport to Germany

<b>Polystyrene (PS)</b>	L	50 - 210	10	12.5 - 20	F
<b>Polyurethane (PU)</b>	L	84 – 166.25	18	10 – 12.5	F
<b>Sheep wool</b>	H	14 – 16	30 - 50	20	R
<b>Foam glass</b>	H	64-219.375	80-110	20-22.5	W
<b>Cellulose (loose)</b>	H	11-18	18-21	20-22.5	R
<b>Cellulose panels</b>	H		24		

#### 9.4 Energy and emission storage and saving potential from insulation

Table 25: Surface areas (Wanjani and Bauer, 2012)

Surface	Roof	Facade	Floor	Total
Area [Mio. m <sup>2</sup> ]	4694	2304	2850	9848

To use as much waste material as possible and keep the transport to a minimum planning chips are most favorable. From Table 24 the following values are gained:

Material	Availability (high / medium / low)	Primary energy consumption [kWh/m <sup>2</sup> ]	Costs [€/m <sup>2</sup> ]	Thickness [cm]	Type (renewable / fossil / waste)
Planning chips	H	13.75	18 - 23	27.5	W

This gives a material demand for 2,708 Mio. m<sup>3</sup> of wood, which corresponds to 2 708 Mt CO<sub>2</sub>, as stated in chapter 3.4.3 above.

This corresponds to a primary energy demand of 135 TWh.

In contrast the insulation with common materials consumes 768 TWh using mineral fiber or 1,280 TWh Polystyrene (PS) of primary energy.

The emissions during production for  $U = 0.2 \text{ W}/(\text{K}\cdot\text{m}^2)$  can be estimated as follows:

Material	Req. Volume [Mio. m <sup>3</sup> ]	Req. weight [Mio. kg] (NRW)	Emissions [kg CO <sub>2</sub> -eq. / kg-insulation] (NRW)	Emissions [Mt CO <sub>2</sub> -eq.]
Wood	2,708	270,800	0.02	5.42
PS	1,600.3	44,008.25	154.36	6,793.11

### 9.5 Energy consumption and emission storage from walls, roofs and floors

Assuming that the average total volume of walls inside a building is double the volume of outer ones (also accounting for thicker outer walls) results the following Table 26:

**Table 26: Emissions storage capacity in building material**

	Area [Mio. m <sup>2</sup> ]	Volume <sup>34</sup> [Mio. m <sup>3</sup> ]	Emission [Mt CO <sub>2</sub> -eq.]		Annual emissions <sup>35</sup> [Mt CO <sub>2</sub> -eq./a]	
			Conventio nal	Wooden	Conv.	Wood
<b>Outer</b>	9848	3594.52	935560	472704	10.40	5.25
<b>Inner</b>	19696	7189.04	1871120	945408	20.79	10.50
<b>Total</b>	29544	10783.56	2806680	1418112	31.19	15.76

This results in a saving potential of 15.43 Mt CO<sub>2</sub>-eq./a and a storage capacity of 10 783.56 Mt CO<sub>2</sub> over the average lifetime of 90 years.

<sup>34</sup> Assuming an average thickness of 0.365 m.

<sup>35</sup> Assuming a lifetime of 90 years. (Dederich Ludger, 2002)

## 9.6 Energy prices

For the cost simulations the following prices have been used:

### Fossil

<b>Fuel</b>	<b>Gas</b>	<b>Oil</b>	<b>District heating</b>	<b>Electricity</b>	<b>Coal</b>	<b>Others</b>
<b>Energy price [€/kWh]</b>	0.06	0.07	0.08	0.234	0.05	0.10

### Renewable

<b>Fuel</b>	<b>Heat pumps</b>	<b>Biomass / waste</b>	<b>Solar</b>
<b>Energy price [€/kWh]</b>	See electricity	0.05	0

## 9.7 Sensitivity analysis

The sensitivity analysis is performed as described in chapter 3.7.

For all cases  $2\Delta k=0,001697143$ .

	WAvg.EAC	WAvg.S	WAvg.SNetE	WAvg.EmS	TotEmS	TotSDeLE
	€/a	€/a	kWh/a	Mt CO <sub>2</sub> -eq./a	Mt CO <sub>2</sub> -eq./a	TWh/a
<b>+1%</b>	3644.4	609.1	5653.3	2.143	444.3	1172.3
<b>-1%</b>	3644.4	597.1	5653.3	2.143	444.3	1172.3
<b>baseline</b>	3644.4	603.1	5653.3	2.143	444.3	1172.3
<b>y<sup>+</sup>-y<sup>-</sup></b>	0.0016971428 5714286	0.0016971 428571428 6	0.0016971428 5714286	0.00169714 285714286	0.0016971 428571428 6	0.00170
<b>k<sub>j</sub>/y<sub>i</sub></b>	0	12	0	0	0	0
<b>S<sub>ij</sub></b>	0.0000721106 354955548	0.0004357 486320676 51	0.0000464861 23149311	0.12263182 454503	0.0005914 922349763 67	0.0002241 746993090 51

	WAvg.CE	WAvg.AC	Cef TotSDeLE	Cef TotEmS	Cef WAvg.CE	Cef WAvg.AC
<b>Units</b>	€/ (kWh*a)	€/ (Mt CO <sub>2</sub> -eq.*a)	TWh/ a	Mt CO <sub>2</sub> -eq./ a	€/ (kWh*a)	€/ (Mt CO <sub>2</sub> -eq.*a)
<b>+1%</b>	0.467	378.7	543.7	253.5	-0.264	-161.3
<b>-1%</b>	0.478	383.6	543.7	253.43	-0.258	-158.5
<b>baseline</b>	0.473	381.1	543.7	253.43	-0.261	-159.9
<b>y<sup>+</sup>-y<sup>-</sup></b>	0.0016971 428571428 6	0.0016971428 5714286	0.001697142 85714286	0.001697142 85714286	0.00169714 285714286	0.00169714285 714286
<b>k<sub>j</sub>/y<sub>i</sub></b>	-0.011	-4.90	0	0.070	-0.0060	-2.80
<b>S<sub>ij</sub></b>	0.5556025 36997886	0.0006895827 86670165	0.000483354 791245172	0.001036972 73408831	-1.00689655	-0.0016435272

## 9.8 Estimation of subsidies and efficiencies

The following table gives an overview of the measures and the corresponding savings and subsidies required. Entries which are bold can be applied totally cost efficient in the specific building types to reduce the emissions.

Measure	TotSDelE TWh/y	TotEmS MtCO2/y	En left TWh/y	Em left MtCO2/y	Subsidies bn.€	Sub. efficiency bn. €/Mt
Bldg. type 1						
<b>1</b>	<b>0,1</b>	<b>5,58</b>	<b>0</b>	<b>0</b>	<b>0,305</b>	<b>0</b>
2	28,7	9,42	28,7	9,42	5,683	0,60
4	8,2	2,77	8,2	2,77	2,990	1,08
<b>6</b>	<b>4,6</b>	<b>10,36</b>	<b>-0,03</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>7</b>	<b>5,6</b>	<b>8,32</b>	<b>0,02</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>8</b>	<b>1,9</b>	<b>6,59</b>	<b>-0,02</b>	<b>0</b>	<b>0</b>	<b>0</b>
9	111,7	32,59	94,41	27,79	15,14197399	0,54
10	199,6	54,84	76,14	23,76	14,906	0,63
11	0,8	5,41	0,81	5,41	5,512	1,02
12	-2,6	1,71	3,92	1,31	0,838	0,64
2						
<b>1</b>	<b>0,6</b>	<b>1,58</b>	<b>0,05</b>	<b>0</b>	<b>0</b>	<b>0</b>
2	11,3	3,38	11,3	3,38	2,162	0,64
4	2,8	0,96	2,8	0,96	1,353	1,41
<b>6</b>	<b>2,4</b>	<b>3,42</b>	<b>0,04</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>7</b>	<b>2,5</b>	<b>2,59</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>8</b>	<b>1,1</b>	<b>1,95</b>	<b>-0,04</b>	<b>0</b>	<b>0</b>	<b>0</b>
9	18,5	5,93	18,5	5,93	5,770	0,97
10	49,6	14,48	49,6	14,48	6,705	0,46
11	0,2	1,3	0,2	1,3	2,494	1,92
<b>12</b>	<b>3,9</b>	<b>1,56</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
3						
<b>1</b>	<b>0</b>	<b>6,46</b>	<b>-0,04</b>	<b>0</b>	<b>0,0318</b>	<b>X</b>
<b>3</b>	<b>46,3</b>	<b>17,68</b>	<b>0,03</b>	<b>0</b>	<b>0,702</b>	<b>X</b>
<b>5</b>	<b>27,4</b>	<b>8,97</b>	<b>0,05</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>6</b>	<b>4,8</b>	<b>10,79</b>	<b>0,04</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>7</b>	<b>4,6</b>	<b>8,51</b>	<b>0,02</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>8</b>	<b>2,1</b>	<b>7,36</b>	<b>-0,03</b>	<b>0</b>	<b>0</b>	<b>0</b>
9	163,9	46,1	49,98	15,17	5,922	0,39
10	237	63,65	10,14	3,37	3,082	0,91
11	1	6,13	0,16	1,08	0,862	0,80
<b>12</b>	<b>7,7</b>	<b>4,65</b>	<b>0,05</b>	<b>0</b>	<b>0</b>	<b>X</b>

Measure	TotSDeIE	TotEmS	En left	Em left	Subsidies	Sub. efficiency
	TWh/y	MtCO2/y	TWh/y	MtCO2/y	bn.€	bn. €/Mt
4						
1	0,4	2,18	0,02	0	0	X
3	16,3	6,04	-0,04	0	0,105	X
5	11,1	3,66	-0,03	0	0	0
6	1,9	3,76	-0,03	0	0	0
7	1,8	2,83	0,02	0	0	0
8	1	2,45	0,02	0	0	0
9	48,5	13,81	0	0	2,6835468	0,434934647
10	75,7	20,73	0,01	0	0	0
11	0,3	1,89	-0,01	0	0	0
12	5,7	2,29	0	0	0	0
5						
1	1,2	0,03	1,21	0	0,0000564	X
3	0,1	0,07	-0,03	0	0	X
5	0,1	0,04	-0,03	0	0	X
6	0	0,05	-0,01	0	0	0
7	0	0,04	-0,01	0	0	0
8	0	0,04	0	0	0	0
9	1,1	0,29	21,1	6,17	3	0,43
10	1,2	0,32	-0,05	0	0	0
11	0	0,03	-0,01	0	0	X
12	0,1	0,05	-0,05	0	0	X
6						
1	-0,1	0,12	-0,04	0	0,0646	0
3	0,6	0,27	0,02	0	0	0
5	0,5	0,14	0,05	0	0	0
6	0	0,18	-0,04	0	0	0
7	0	0,15	-0,03	0	0	0
8	0	0,14	0	0	0	0
9	4,6	1,24	0,03	0	0	0
10	5,4	1,4	-0,04	0	0	0
11	0	0,14	-0,02	0	0	0
12	3,8	1,03	-0,03	0	0	0

Measure	TotSDeIE	TotEmS	En left	Em left	Subsidies	Sub. efficiency
	TWh/y	MtCO2/y	TWh/y	MtCO2/y	bn.€	bn. €/Mt
7						
1	0,2	0,29	-0,02	0	0	0
3	2,7	0,89	0,03	0	0,0308	0
5	1,6	0,54	-0,03	0	0	0
6	0,5	0,56	0,02	0	0	0
7	0,4	0,39	0	0	0	0
8	0,3	0,33	0,02	0	0	0
9	3,8	1,16	0,04	0	0,553	2,096
10	7,9	2,3	0,03	0	0,229	0
11	0	0,2	-0,02	0	0	0
12	-0,9	-0,13	-0,04	0	0,0498	0
8						
1	0	0,11	-0,01	0	0	0
3	0,8	0,29	0,03	0	0,00236	0
5	0,5	0,17	-0,03	0	0	0
6	0,1	0,18	0,01	0	0	0
7	0,1	0,14	0,02	0	0	0
8	0	0,12	-0,04	0	0	0
9	2,7	0,75	0,04	0	0,106702	0
10	3,9	1,05	0,03	0	0	0
11	0	0,1	-0,02	0	0	0
12	1,1	0,31	0,04	0	0	0
Sum	580,3	158,77	379,76	123,46	76,660	0,621

The following Table 27 shows the subsidies necessary to achieve cost neutrality (for the final consumer), as described in chapter 5.1.

The ranking uses the following scale to compare the measures: high (<0.01), medium (0.01<x<2), low (>2)

**Table 27: Close to financial beneficial measures I**

<b>Building type</b>	<b>Measure</b>	<b>WAvg.CE [€/ (kWh*a)]</b>	<b>Additional saving potential [Mt CO<sub>2</sub>-eq./a (TWh/a)]</b>	<b>Subsidy volume [bn. €/a]</b>	<b>Efficiency [bn. €/Mt CO<sub>2</sub>-eq.]</b>	<b>Cost efficiency ranking (H/M/L)</b>
<b>1</b>	Ventilation SFD	13.1	9.42 (28.7)	5.68	0.6	M
<b>1</b>	Hot water SFD	96.7	2.77 (8.2)	2.99	1.08	M
<b>1</b>	All Pathway ESM	-24.8	7.82 (25.24)	9.38	1.2	M
<b>1</b>	Solar thermal	747.9	5.41 (0.81)	5.51	1.02	M
<b>1</b>	DH	-226.8	1.31 (3.92)	0.84	0.64	M
<b>2</b>	Ventilation SFD	14.3	3.38 (11.3)	2,16234	0.64	M
<b>2</b>	Hot water SFD	160.9	0.96 (2.8)	1,35314	1.41	M
<b>2</b>	All ESM	66	10 (33.48)	5,01386	0.5	M
<b>2</b>	Solar thermal	1619.2	1.3 (0.2)	2,49425	1.92	M
<b>3</b>	Ventilation MFD	-102.5	0 (0.03)	0.70178	X	X
<b>3</b>	Solar	-52.3	1.08	0.86167	0.8	M

	thermal		(0.16)			
<b>5</b>	Ventilation MFD	459.3	5.9 (1.8)	0.00067	0.00011	H
<b>5</b>	Hot water MFD	299.1	5.03 (14.1)	0.00053	0.00011	H
<b>5</b>	Solar thermal	747.9	5.41 (0.81)	0.00098	0.00018	H
<b>5</b>	DH	-226.8	1.31 (3.92)	0.33913	0.26	M
<b>7</b>	Ventilation MFD	-119.5	0 (0.03)	0.03082	X	X
<b>7</b>	All ESM	-142.9	0 (0.03)	0.02407	X	X
<b>8</b>	Ventilation MFD	-121.3	0 (0.03)	0,00236	X	X
<b>Sum</b>	N/A	N/A	60.02 (135.24)	37.95	1.58	M

Table 28: Close to beneficial measures II

Building type	Measure	Additional saving potential [Mt CO <sub>2</sub> -eq./a]	Additional saving potential [TWh/a]	Subsidy volume [bn. €/a]	Cost efficiency [bn. €/Mt CO <sub>2</sub> -eq.]	Cost efficiency ranking (H/M/L)
1	PHPP	38.87	137.5	247.51	6.37	L
1	100% gas	6.39	4.1	42.51	6.65	L
1	EnEV	33.18	114.1	237.96	7.17	L
2	PHPP	7.05	23.1	12.65	1.79	M
2	100% gas	1.52	1	1.64	1.08	M
2	100% geothermal	0	0.03	0.59	X	X
2	EnEV09	6.02	18.9	12.71	2.11	L
3	PHPP	44.18	159.33	34.89	0.79	M
3	100% gas	7.38	4.73	6.37	0.86	M
3	100% geothermal	0	0.02	3.31	X	X
3	EnEV09	46.09	164.14	41.14	0.89	M
4	PHPP	11.73	41.63	6.80	0.58	M
4	100% gas	2.39	1.5	1.41	0.59	M
4	EnEV	10.58	36.94	6.46	0.61	M
5	PHPP	38.87	137.5	0.04	0.0011	H
5	100% gas	6.39	4.1	0.0075	0.0012	H
5	EnEV	33.18	114.1	0.042	0.0013	H
6	PHPP	1.35	5	0.61	0.45	M
6	100% gas	0.16	0,1	0.10	0.62	M
6	EnEV	1.26	4.6	0.59	0.47	M

<b>7</b>	PHPP	1.35	4.6	1.60	1.18	M
<b>7</b>	100% gas	0.21	0.1	0.28	1.35	M
<b>7</b>	EnEV	1.18	3.9	1.53	1.29	M
<b>8</b>	PHPP	0.85	3.1	0.45	0.53	M
<b>8</b>	100% gas	0.12	0.1	0.08	0.63	M
<b>8</b>	EnEV	0.76	2.7	0.43	0.57	M

Geothermal energy systems can be introduced in the whole building stock cost efficient in all buildings. The subsidies stated above just save further energy.

## 9.9 Current input file

Figure 9 shows the initial input values and characteristics for the German building stock.

Building number	Location_no	Byggnads-typ	TC	Wc	Wf	T0	Trmin	Trmax
110	1	SubtyR1	75774218,32	0,95	0,7	18	18	25
111	1	SubtyR1	92599000	0,988506	0,7	18	18	25
112	1	SubtyR1	149966412,8	0,95	0,7	18	18	25
113	1	SubtyR1	61703683	0,95	0,7	18	18	25
114	1	SubtyR1	137164336	0,95	0,7	18	18	25
115	1	SubtyR1	114143737,5	0,95	0,7	18	18	25
116	1	SubtyR1	109926940	0,95	0,7	18	18	25
117	1	SubtyR1	93594437,94	0,95	0,7	18	18	25
118	1	SubtyR1	69996034,5	0,7875	0,7	18	18	25
119	1	SubtyR1	88996825,5	0,7875	0,7	18	18	25
120	1	SubtyR2	44632535,33	0,95	0,7	18	18	25
122	1	SubtyR2	53256711,04	0,875	0,7	18	18	25
123	1	SubtyR2	80497388	1	0,7	18	18	25
124	1	SubtyR2	56351166,1	0,95	0,7	18	18	25
125	1	SubtyR2	63237399,61	0,95	0,7	18	18	25
126	1	SubtyR2	52135282,95	0,95	0,7	18	18	25
127	1	SubtyR2	62348940	0,95	0,7	18	18	25
128	1	SubtyR2	70515442,63	0,7875	0,7	18	18	25
129	1	SubtyR2	84890257,13	0,7875	0,7	18	18	25
130	1	SubtyR3	133351420,8	0,95	0,7	18	18	25
131	1	SubtyR3	296339479	0,95	0,7	18	18	25
132	1	SubtyR3	193649821,4	0,95	0,7	18	18	25
133	1	SubtyR3	328292948,4	0,875	0,7	18	18	25
134	1	SubtyR3	1597874946	0,95	0,7	18	18	25

135	1	SubtyR3	291599072,1	0,875	0,7	18	18	25
136	1	SubtyR3	328454382,5	0,95	0,7	18	18	25
137	1	SubtyR3	440970447,3	0,95	0,7	18	18	25
138	1	SubtyR3	454991403,8	0,7875	0,7	18	18	25
139	1	SubtyR3	1176079034	0,7875	0,7	18	18	25
140	1	SubtyR4	343917403,2	0,95	0,7	18	18	25
142	1	SubtyR4	745398110,9	0,95	0,7	18	18	25
143	1	SubtyR4	853350031	0,95	0,7	18	18	25
144	1	SubtyR4	2060105472	0,988506	0,7	18	18	25
145	1	SubtyR4	2030447100	0,95	0,7	18	18	25
154	1	SubtyR5	5648086064	0,95	0,7	18	18	25
155	1	SubtyR5	11745632560	0,875	0,7	18	18	25
210	2	SubtyR1	75774218,32	0,95	0,7	18	18	25
211	2	SubtyR1	92599000	0,988506	0,7	18	18	25
212	2	SubtyR1	149966412,8	0,95	0,7	18	18	25
213	2	SubtyR1	61703683	0,95	0,7	18	18	25
214	2	SubtyR1	137164336	0,95	0,7	18	18	25
215	2	SubtyR1	114143737,5	0,95	0,7	18	18	25
216	2	SubtyR1	109926940	0,95	0,7	18	18	25
217	2	SubtyR1	93594437,94	0,95	0,7	18	18	25
218	2	SubtyR1	69996034,5	0,7875	0,7	18	18	25
219	2	SubtyR1	88996825,5	0,7875	0,7	18	18	25
220	2	SubtyR2	44632535,33	0,95	0,7	18	18	25
222	2	SubtyR2	53256711,04	0,875	0,7	18	18	25
223	2	SubtyR2	80497388	1	0,7	18	18	25
224	2	SubtyR2	56351166,1	0,95	0,7	18	18	25
225	2	SubtyR2	63237399,61	0,95	0,7	18	18	25
226	2	SubtyR2	52135282,95	0,95	0,7	18	18	25

<b>227</b>	2	SubtyR2	62348940	0,95	0,7	18	18	25
<b>228</b>	2	SubtyR2	70515442,63	0,7875	0,7	18	18	25
<b>229</b>	2	SubtyR2	84890257,13	0,7875	0,7	18	18	25
<b>230</b>	2	SubtyR3	133351420,8	0,95	0,7	18	18	25
<b>231</b>	2	SubtyR3	296339479	0,95	0,7	18	18	25
<b>232</b>	2	SubtyR3	193649821,4	0,95	0,7	18	18	25
<b>233</b>	2	SubtyR3	328292948,4	0,875	0,7	18	18	25
<b>234</b>	2	SubtyR3	1597874946	0,95	0,7	18	18	25
<b>235</b>	2	SubtyR3	291599072,1	0,875	0,7	18	18	25
<b>236</b>	2	SubtyR3	328454382,5	0,95	0,7	18	18	25
<b>237</b>	2	SubtyR3	440970447,3	0,95	0,7	18	18	25
<b>238</b>	2	SubtyR3	454991403,8	0,7875	0,7	18	18	25
<b>239</b>	2	SubtyR3	1176079034	0,7875	0,7	18	18	25
<b>2310</b>	2	SubtyR6	974446199	0,988506	0,7	18	18	25
<b>2311</b>	2	SubtyR6	1368213219	0,988506	0,7	18	18	25
<b>240</b>	2	SubtyR4	343917403,2	0,95	0,7	18	18	25
<b>242</b>	2	SubtyR4	745398110,9	0,95	0,7	18	18	25
<b>243</b>	2	SubtyR4	853350031	0,95	0,7	18	18	25
<b>244</b>	2	SubtyR4	2060105472	0,988506	0,7	18	18	25
<b>245</b>	2	SubtyR4	2030447100	0,95	0,7	18	18	25
<b>2410</b>	2	SubtyR7	1844769595	0,988506	0,7	18	18	25
<b>2411</b>	2	SubtyR7	1504385915	0,95	0,7	18	18	25
<b>2412</b>	2	SubtyR7	1570230794	0,95	0,7	18	18	25
<b>254</b>	2	SubtyR5	5648086064	0,95	0,7	18	18	25
<b>255</b>	2	SubtyR5	11745632560	0,875	0,7	18	18	25
<b>2510</b>	2	SubtyNR1	3170065690	0,95	0,7	18	18	25
<b>2511</b>	2	SubtyNR1	3860557570	0,95	0,7	18	18	25
<b>310</b>	3	SubtyR1	75774218,32	0,95	0,7	18	18	25

<b>311</b>	3	SubtyR1	92599000	0,988506	0,7	18	18	25
<b>312</b>	3	SubtyR1	149966412,8	0,95	0,7	18	18	25
<b>313</b>	3	SubtyR1	61703683	0,95	0,7	18	18	25
<b>314</b>	3	SubtyR1	137164336	0,95	0,7	18	18	25
<b>315</b>	3	SubtyR1	114143737,5	0,95	0,7	18	18	25
<b>316</b>	3	SubtyR1	109926940	0,95	0,7	18	18	25
<b>317</b>	3	SubtyR1	93594437,94	0,95	0,7	18	18	25
<b>318</b>	3	SubtyR1	69996034,5	0,7875	0,7	18	18	25
<b>319</b>	3	SubtyR1	88996825,5	0,7875	0,7	18	18	25
<b>320</b>	3	SubtyR2	44632535,33	0,95	0,7	18	18	25
<b>322</b>	3	SubtyR2	53256711,04	0,875	0,7	18	18	25
<b>323</b>	3	SubtyR2	80497388	1	0,7	18	18	25
<b>324</b>	3	SubtyR2	56351166,1	0,95	0,7	18	18	25
<b>325</b>	3	SubtyR2	63237399,61	0,95	0,7	18	18	25
<b>326</b>	3	SubtyR2	52135282,95	0,95	0,7	18	18	25
<b>327</b>	3	SubtyR2	62348940	0,95	0,7	18	18	25
<b>328</b>	3	SubtyR2	70515442,63	0,7875	0,7	18	18	25
<b>329</b>	3	SubtyR2	84890257,13	0,7875	0,7	18	18	25
<b>330</b>	3	SubtyR3	133351420,8	0,95	0,7	18	18	25
<b>331</b>	3	SubtyR3	296339479	0,95	0,7	18	18	25
<b>332</b>	3	SubtyR3	193649821,4	0,95	0,7	18	18	25
<b>333</b>	3	SubtyR3	328292948,4	0,875	0,7	18	18	25
<b>334</b>	3	SubtyR3	1597874946	0,95	0,7	18	18	25
<b>335</b>	3	SubtyR3	291599072,1	0,875	0,7	18	18	25
<b>336</b>	3	SubtyR3	328454382,5	0,95	0,7	18	18	25
<b>337</b>	3	SubtyR3	440970447,3	0,95	0,7	18	18	25
<b>338</b>	3	SubtyR3	454991403,8	0,7875	0,7	18	18	25
<b>339</b>	3	SubtyR3	1176079034	0,7875	0,7	18	18	25

<b>3310</b>	3	SubtyR6	974446199	0,988506	0,7	18	18	25
<b>3311</b>	3	SubtyR6	1368213219	0,988506	0,7	18	18	25
<b>340</b>	3	SubtyR4	343917403,2	0,95	0,7	18	18	25
<b>342</b>	3	SubtyR4	745398110,9	0,95	0,7	18	18	25
<b>343</b>	3	SubtyR4	853350031	0,95	0,7	18	18	25
<b>344</b>	3	SubtyR4	2060105472	0,988506	0,7	18	18	25
<b>345</b>	3	SubtyR4	2030447100	0,95	0,7	18	18	25
<b>3410</b>	3	SubtyR4	1844769595	0,988506	0,7	18	18	25
<b>3411</b>	3	SubtyR4	1504385915	0,95	0,7	18	18	25
<b>3412</b>	3	SubtyR4	1570230794	0,95	0,7	18	18	25
<b>354</b>	3	SubtyR5	5648086064	0,95	0,7	18	18	25
<b>355</b>	3	SubtyR5	11745632560	0,875	0,7	18	18	25
<b>3510</b>	3	SubtyNR1	3170065690	0,95	0,7	18	18	25
<b>3511</b>	3	SubtyNR1	3860557570	0,95	0,7	18	18	25

Sh	Sc	Pc	Ph	Oc	SFP	HRec_eff	Lc	Hw	EfHeat	EfCool
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.1635	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.11	0	0	0.2773	1.334	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1







2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	1.43	0	0	0.2773	2.464	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.377	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.308	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.308	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.308	1	1
2000000	-2000000	5000000	5000000	2	0	0	0.2773	3.308	1	1

EfHotW	HyP	PerHPinH	Weight	Ts	A	U	S	Sw	P_HPa
1	0,4	0	464479,7001	0,76	149,038	1,642623	196,04	22,3	0,49
1	0,4	0	165247,4014	0,86	137,873	2,060288	171,78	28,78	0,49
1	0,4	0	571667,6179	0,76	135,156	1,570502	237,3	52,35	0,49
1	0,4	0	410885,7412	0,76	138,043	1,173555	119,8	18,4	0,49
1	0,4	0	705652,5152	0,76	139,837	1,38764	185,33	45,15	0,49
1	0,4	0	656524,081	0,76	144,898	1,101627	170,55	34,21	0,49
1	0,4	0	334961,2853	0,76	148	1,030434	161,4	27	0,49
1	0,4	0	464479,7001	0,76	142,307	0,727697	213,3	29,67	0,49
1	0,4	0	482344,6724	0,63	140,74	0,518595	128,6	32,46	0,49
1	0,4	0	352826,2576	0,63	144,303	0,456853	190,86	28,3	0,49
1	0,4	0	156315,3942	0,76	122,857	1,414429	76,47	18,091	0,49
1	0,4	0	357291,7823	0,7	113,75	1,629775	66,14	21,48	0,49
1	0,4	0	214374,8778	0,8	118,75	1,342804	136,66	46,67	0,49
1	0,4	0	299232,2987	0,76	113,43	1,464703	42,42	13,52	0,49
1	0,4	0	290300,2915	0,76	120	1,328433	55,72	23,36	0,49
1	0,4	0	169713,8839	0,76	123,684	0,798552	56,1	20,24	0,49
1	0,4	0	241171,8572	0,76	122,222	0,800837	52,9	18,75	0,49
1	0,4	0	223307,8428	0,63	124	0,524174	45,2	22,4	0,49
1	0,4	0	133984,8973	0,63	123,333	0,412251	142,7	36,3	0,49
1	0,4	0	169713,8839	0,76	294,737	2,154133	148	54,08	0,49
1	0,4	0	22330,49693	0,76	260	2,253076	629,13	106,97	0,49
1	0,4	0	205442,8706	0,76	291,304	1,963403	325,54	71,16	0,49
1	0,4	0	164996,4431	0,7	335,897	1,636138	464	98,72	0,49
1	0,4	0	239943,8859	0,76	358,182	1,74466	2041	507,48	0,49

1	0,4	0	142916,9045	0,7	340,624	1,057573	338	81,3	0,49
1	0,4	0	71457,97331	0,76	431,25	0,941971	449,13	99,57	0,49
1	0,4	0	93789,4281	0,76	361,945	0,89248	776,8	161	0,49
1	0,4	0	89322,94557	0,63	595	0,483638	697,8	162,8	0,49
1	0,4	0	31263,46198	0,63	585,714	0,491323	1700	307,1	0,49
1	0,4	0	4466,482528	0,76	1000	2,372541	307,4	136,2	0,49
1	0,4	0	4466,482528	0,76	1700	1,609877	1246	278,52	0,49
1	0,4	0	13398,48973	0,76	1033,33	1,778647	1378	294,9	0,49
1	0,4	0	26328,58787	0,86	1400	2,051064	3249,79	687,03	0,49
1	0,4	0	43529,76592	0,76	1667	1,706093	2132	545	0,49
1	0,4	0	468,391584	0,76	1400	2,037009	5579,16	1947,19	0,49
1	0,4	0	348,659584	0,7	1667	1,308594	10093,9	2580,52	0,49
1	0,4	0	328324,3011	0,76	149,038	1,642623	196,04	22,3	0,49
1	0,4	0	116807,6656	0,86	137,873	2,060288	171,78	28,78	0,49
1	0,4	0	404091,6686	0,76	135,156	1,570502	237,3	52,35	0,49
1	0,4	0	290440,1385	0,76	138,043	1,173555	119,8	18,4	0,49
1	0,4	0	498800,6384	0,76	139,837	1,38764	185,33	45,15	0,49
1	0,4	0	464073,5692	0,76	144,898	1,101627	170,55	34,21	0,49
1	0,4	0	236772,4246	0,76	148	1,030434	161,4	27	0,49
1	0,4	0	328324,3011	0,76	142,307	0,727697	213,3	29,67	0,49
1	0,4	0	340951,7168	0,63	140,74	0,518595	128,6	32,46	0,49
1	0,4	0	249399,8403	0,63	144,303	0,456853	190,86	28,3	0,49
1	0,4	0	110493,4789	0,76	122,857	1,414429	76,47	18,091	0,49
1	0,4	0	252556,9337	0,7	113,75	1,629775	66,14	21,48	0,49
1	0,4	0	151533,7771	0,8	118,75	1,342804	136,66	46,67	0,49
1	0,4	0	211516,6355	0,76	113,43	1,464703	42,42	13,52	0,49

1	0,4	0	205202,4487	0,76	120	1,328433	55,72	23,36	0,49
1	0,4	0	119964,759	0,76	123,684	0,798552	56,1	20,24	0,49
1	0,4	0	170476,3373	0,76	122,222	0,800837	52,9	18,75	0,49
1	0,4	0	157847,9638	0,63	124	0,524174	45,2	22,4	0,49
1	0,4	0	94708,96986	0,63	123,333	0,412251	142,7	36,3	0,49
1	0,4	0	119964,759	0,76	294,737	2,154133	148	54,08	0,49
1	0,4	0	15784,50902	0,76	260	2,253076	629,13	106,97	0,49
1	0,4	0	145220,5482	0,76	291,304	1,963403	325,54	71,16	0,49
1	0,4	0	116629,5044	0,7	335,897	1,636138	464	98,72	0,49
1	0,4	0	169607,5619	0,76	358,182	1,74466	2041	507,48	0,49
1	0,4	0	101023,1566	0,7	340,624	1,057573	338	81,3	0,49
1	0,4	0	50511,5783	0,76	431,25	0,941971	449,13	99,57	0,49
1	0,4	0	66296,08733	0,76	361,945	0,89248	776,8	161	0,49
1	0,4	0	63138,99395	0,63	595	0,483638	697,8	162,8	0,49
1	0,4	0	22098,69578	0,63	585,714	0,491323	1700	307,1	0,49
1	0,4	0	14692,55318	0,86	335,897	1,874136	1160,16	319,9	0,49
1	0,4	0	9110,168416	0,86	358,182	2,174421	1482,48	547	0,49
1	0,4	0	3157,093376	0,76	1000	2,372541	307,4	136,2	0,49
1	0,4	0	3157,093376	0,76	1700	1,609877	1246	278,52	0,49
1	0,4	0	9471,280128	0,76	1033,33	1,778647	1378	294,9	0,49
1	0,4	0	18611,14208	0,86	1400	2,051064	3249,79	687,03	0,49
1	0,4	0	30769,20829	0,76	1667	1,706093	2132	545	0,49
1	0,4	0	11611,13043	0,86	1667	1,783668	1601,73	461	0,49
1	0,4	0	10002,89021	0,76	1667	1,238755	1675,73	387	0,49
1	0,4	0	9080,47488	0,76	1667	1,141668	1675,73	387	0,49
1	0,4	0	330,46032	0,76	1400	2,037009	5579,16	1947,19	0,49

1	0,4	0	246,168992	0,7	1667	1,308594	10093,9	2580,52	0,49
1	0,4	0	5537,365536	0,76	1667	1,789978	2994,09	756	0,49
1	0,4	0	748,085536	0,76	1667	1,627517	4223,74	1471,06	0,49
1	0,4	0	203366,2388	0,76	149,038	1,642623	196,04	22,3	0,49
1	0,4	0	72351,65296	0,86	137,873	2,060288	171,78	28,78	0,49
1	0,4	0	250296,3935	0,76	135,156	1,570502	237,3	52,35	0,49
1	0,4	0	179900,6825	0,76	138,043	1,173555	119,8	18,4	0,49
1	0,4	0	308960,2842	0,76	139,837	1,38764	185,33	45,15	0,49
1	0,4	0	287450,6699	0,76	144,898	1,101627	170,55	34,21	0,49
1	0,4	0	146658,29	0,76	148	1,030434	161,4	27	0,49
1	0,4	0	203366,2388	0,76	142,307	0,727697	213,3	29,67	0,49
1	0,4	0	211188,0909	0,63	140,74	0,518595	128,6	32,46	0,49
1	0,4	0	154480,1421	0,63	144,303	0,456853	190,86	28,3	0,49
1	0,4	0	68440,72691	0,76	122,857	1,414429	76,47	18,091	0,49
1	0,4	0	156435,1262	0,7	113,75	1,629775	66,14	21,48	0,49
1	0,4	0	93861,2673	0,8	118,75	1,342804	136,66	46,67	0,49
1	0,4	0	131014,5858	0,76	113,43	1,464703	42,42	13,52	0,49
1	0,4	0	127103,6598	0,76	120	1,328433	55,72	23,36	0,49
1	0,4	0	74306,63706	0,76	123,684	0,798552	56,1	20,24	0,49
1	0,4	0	105594,0454	0,76	122,222	0,800837	52,9	18,75	0,49
1	0,4	0	97772,19334	0,63	124	0,524174	45,2	22,4	0,49
1	0,4	0	58662,93286	0,63	123,333	0,412251	142,7	36,3	0,49
1	0,4	0	74306,63706	0,76	294,737	2,154133	148	54,08	0,49
1	0,4	0	9776,836192	0,76	260	2,253076	629,13	106,97	0,49
1	0,4	0	89950,34125	0,76	291,304	1,963403	325,54	71,16	0,49
1	0,4	0	72241,49952	0,7	335,897	1,636138	464	98,72	0,49

1	0,4	0	105056,6882	0,76	358,182	1,74466	2041	507,48	0,49
1	0,4	0	62573,85891	0,7	340,624	1,057573	338	81,3	0,49
1	0,4	0	31287,40838	0,76	431,25	0,941971	449,13	99,57	0,49
1	0,4	0	41064,24458	0,76	361,945	0,89248	776,8	161	0,49
1	0,4	0	39109,26048	0,63	595	0,483638	697,8	162,8	0,49
1	0,4	0	13687,76224	0,63	585,714	0,491323	1700	307,1	0,49
1	0,4	0	5003,839744	0,86	335,897	1,874136	1160,16	319,9	0,49
1	0,4	0	3102,495584	0,86	358,182	2,174421	1482,48	547	0,49
1	0,4	0	1954,984096	0,76	1000	2,372541	307,4	136,2	0,49
1	0,4	0	1954,984096	0,76	1700	1,609877	1246	278,52	0,49
1	0,4	0	5865,910144	0,76	1033,33	1,778647	1378	294,9	0,49
1	0,4	0	11527,79696	0,86	1400	2,051064	3249,79	687,03	0,49
1	0,4	0	19058,46083	0,76	1600	1,706093	2132	545	0,49
1	0,4	0	3954,029568	0,86	1667	1,783668	1601,73	461	0,49
1	0,4	0	3407,093792	0,76	1667	1,238755	1675,73	387	0,49
1	0,4	0	3091,959168	0,76	1667	1,141668	1675,73	387	0,49
1	0,4	0	204,981184	0,76	1400	2,037009	5579,16	1947,19	0,49
1	0,4	0	152,299104	0,7	1667	1,308594	10093,9	2580,52	0,49
1	0,4	0	1886,018464	0,76	1667	1,789978	2994,09	756	0,49
1	0,4	0	254,789696	0,76	1667	1,627517	4223,74	1471,06	0,49

P_HP b	P_HP c	P_HP	P_Sh _O	P_Sh _G	P_Sh _P	P_W_ SH	P_Sh _EB	P_Sh _ED	P_Sh _OF	P_Sh _DH	P_Sh _E	P_Sh _W
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	10,10	55,4	0	0	14,8	0	5,2	3,8	16,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5

0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,30	55,7	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5

0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5

0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
0,86	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
0,86	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5

<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
<b>0,86</b>	0,14	1,49	11,10	55,4	0	0	13,8	0	5,2	3,8	15,29	9,2
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	33,60	44,3	0	0	3,5	0	5,2	3,9	4,99	6,5
<b>0,86</b>	0,14	1,49	25,80	56,2	0	0	4,3	0	5,2	4	5,79	2,6

P_Sh_E	P_Sh_W	P_Sh_C	P_Sh_A	P_Sh_Tot	P_Hw_O	P_Hw_G	P_Hw_A	P_Hw_EB	P_Hw_W	P_Hw_E
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
15,29	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
16,29	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60



4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
15,29	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
15,29	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60

<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,87	20,20	0	20,20
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
<b>15,29</b>	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,87	20,20	0	20,20
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
<b>5,79</b>	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
<b>15,29</b>	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
<b>4,99</b>	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60

4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
15,29	9,2	0	-0,52	100,00	14,6	48,6	5,17	28,30	0	28,30
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
4,99	6,5	1	-0,02	100,00	31,9	39,3	5,67	19,60	0	19,60
5,79	2,6	0	-0,12	100,00	25,9	48,5	1,77	20,20	0	20,20

<b>P_Hw_Tot</b>	<b>P_Hw_C</b>	<b>P_Hw_OF</b>	<b>P_Hw_DH</b>	<b>P_Hw_P</b>	<b>P_Hw_S</b>	<b>P_Sh_S</b>	<b>P_Sh_C</b>
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1

100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1

100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1

100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	3,1	0	0,53	0,53	0
100,00	0	0	2,8	0	0,53	0,53	0
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1
100,00	0	0	3	0	0,53	0,53	1

<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0
<b>100,00</b>	0	0	2,8	0	0,53	0,53	0
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3	0	0,53	0,53	1
<b>100,00</b>	0	0	3,1	0	0,53	0,53	0

## ***9.10 Changes in the code***

The following major changes were made to the code along with minor adjustments:

- Exclude NR2-NR7 from output (not needed, because empty)
- Calculation timer to measure calculation time
- Introduce solar thermal and others as a fuel

## **Acknowledgement of Original Work**

By submitting this thesis I confirm that the thesis is entirely my own work.

All work other than mine is indicated properly.

Gothenburg, 24<sup>th</sup> June 2013

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(Tillman Gauer)