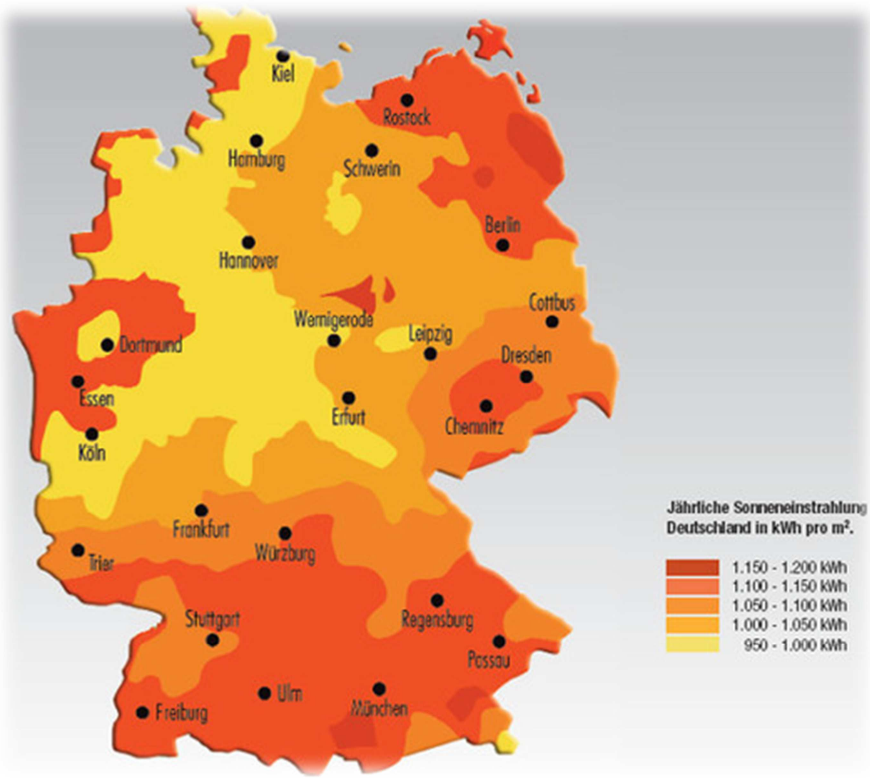

Distribution of annual solar radiation within Germany (1)

Bottom-up characterization of the residential German building stock – Reference buildings and energy demand

Master Thesis for the degree of Mechanical Engineering

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SUPERVISOR
Angela Sasic Kalagasidis
Érika Mata

EXAMINER
Filip Johnsson

Department of Energy and Environment
Division of Energy Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Technical report No T2012-386
Department of Energy and Environment
Division of Energy Technology
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover: Distribution of annual solar radiation within Germany (1)

Chalmers ReproService
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Abstract

In many countries of the European Union, the largest potential for energy efficiency improvements lies in retrofitting houses, since the energy consumption of residential and non-residential buildings in the European Union had the largest share with 39 % in 2009. Currently, there is a lack of information about the building stock and associated modelling tools, which can be used to assess such measurements as basis for energy efficiency strategies and policy design to be applied to the European building sector. Therefore, a methodology has been developed that represents the European building stock as reference buildings with the aim to assess the effects of energy saving measures. The model used for the building energy simulation is the E*nergy Assessment for Buildings Stocks* (EABS). By applying the EABS model, the final energy and heating demand for the German residential stock could be calculated and provided a base for further investigation considering the assessment for retrofitting residential houses in Germany.

Keywords: archetype buildings, German building stock, energy demand, bottom-up modelling, energy simulation, EABS model

Acknowledgements

First of all, we would like to thank our examiner Professor Filip Johnsson for giving the opportunity to develop this master thesis at Chalmers University.

In addition, special thanks to our supervisors Erika Mata and Angela Sasic Kalagasidis for their support, advice, and patience. We especially appreciate the time you offered us for questions belonging to all kind of problems regarding the thesis. Furthermore, we thank you and Filip for the possibility to hold the presentation after our stay in the USA/Germany.

Moreover, we would like to thank Georgina Medina for her tremendous support. Thank you very much for your advice, especially in questions regarding the EABS model.

Furthermore, we thank our family and friends in Gothenburg and Germany, in particular Elle Hansson.

Table of Contents

List of abbreviation

SFD	Single Family Dwelling
MFD	Multiple Family Dwelling
RH	Row House/Terrace House
AP	Apartment Block
HH	High Tower / High-rise building
EAZ	Expenditure factor
IWU	Institute for housing and environment
CO_2	Carbon dioxide
ppm	Parts per million
EABS	Energy Assessment for Building Stock
U-value	Thermal transmittance value
stat. Bundesamt (=statisches Bundesamt)	Federal Statistical Office of Germany in Wiesbaden
TWW (=Trainings- und Weiterbildungszentrum Wolfenbuettel)	Off-the-job training center Wolfenbuettel e.V.
Meteonorm	software that provides wheather data and wheather files

1. Introduction

1.1 Motives for the thesis

Climate change has been occurring throughout Earth's history. Especially over the last hundreds of years humans have altered the atmosphere in an unprecedented manner, and stand to suffer greatly from even relatively minor alterations in climate (2). Since the Industrial Revolution in the late 18th century humans have been affecting the climate significantly by emitting harmful greenhouse gases (for instance, CH_4 and especially CO_2). In Figure 1 the atmospheric CO_2 concentration over the last 1000 years is presented. Thereby, it is visible that the share of CO_2 has increased massively from 280 ppm in the preindustrial era up to 365 ppm in 2000. In Figure 2 the Keeling Curve[1] shows in more detail the development of the carbon dioxide composition over the last 50 years. There it can be seen that the share of CO_2 has increased 60 ppm to 370 ppm in total from 1958 till 2008. Only four years later average values of 400 ppm were measured, a very sharp rise within a short time period (3).

Furthermore, due to the climate change and the related air temperature increase the concerns about rising fuel prices and security of energy supplies are facing vast challenges. Therefore, recently many national and international political incentives have been released to solve those problems. One incentive was the introduction of the Kyoto protocol in 1997, which came into force in 2005. For Germany, the target was to decrease the greenhouse gas emissions 21 % at a level which was measured in 1990. Germany reached that aim already in 2007. Nonetheless, further efforts have been made to be prepared for prospective regulations or initiatives (for instance, "Energy 2020 – A strategy for competitive, sustainable and secure energy" (4)), since the worldwide CO_2 air concentration is still on the rise.

[1] The Keeling Curve is a graph which illustrates the ongoing change in concentration of CO_2 in Earth's atmosphere since 1958.

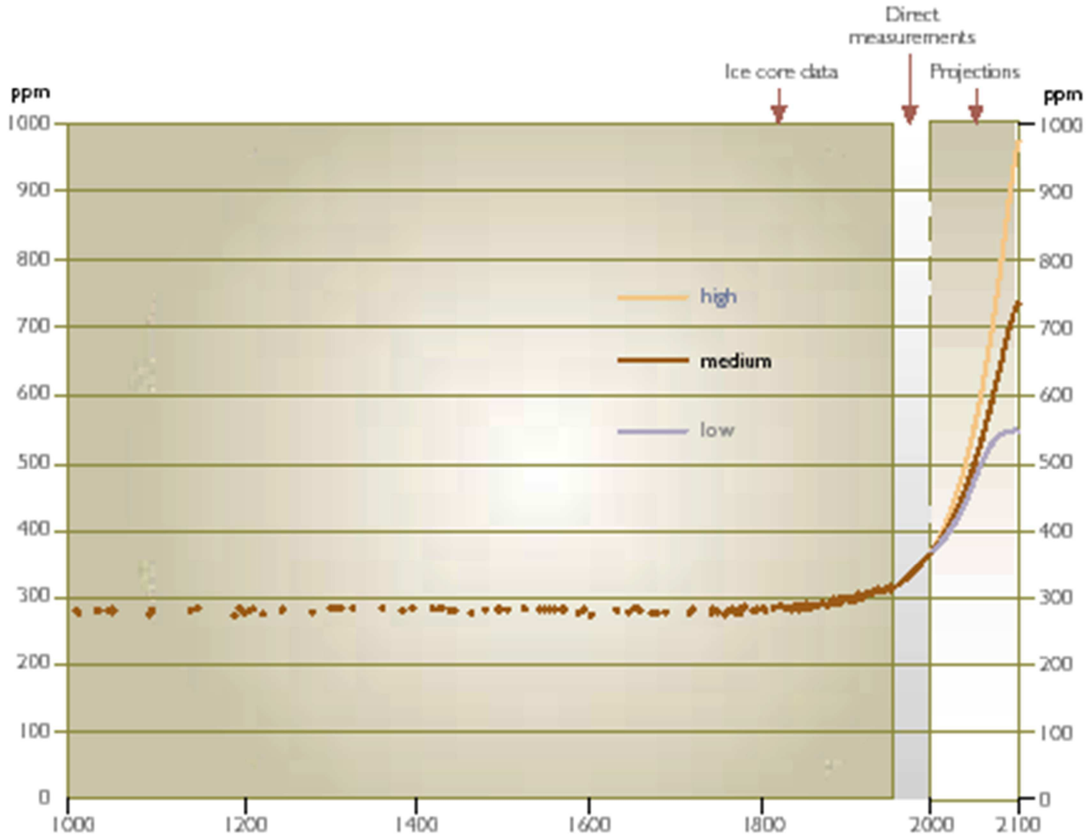

Figure 1: Atmospheric CO_2 concentration from year 1900 till 2000 and possible developments in future (5)

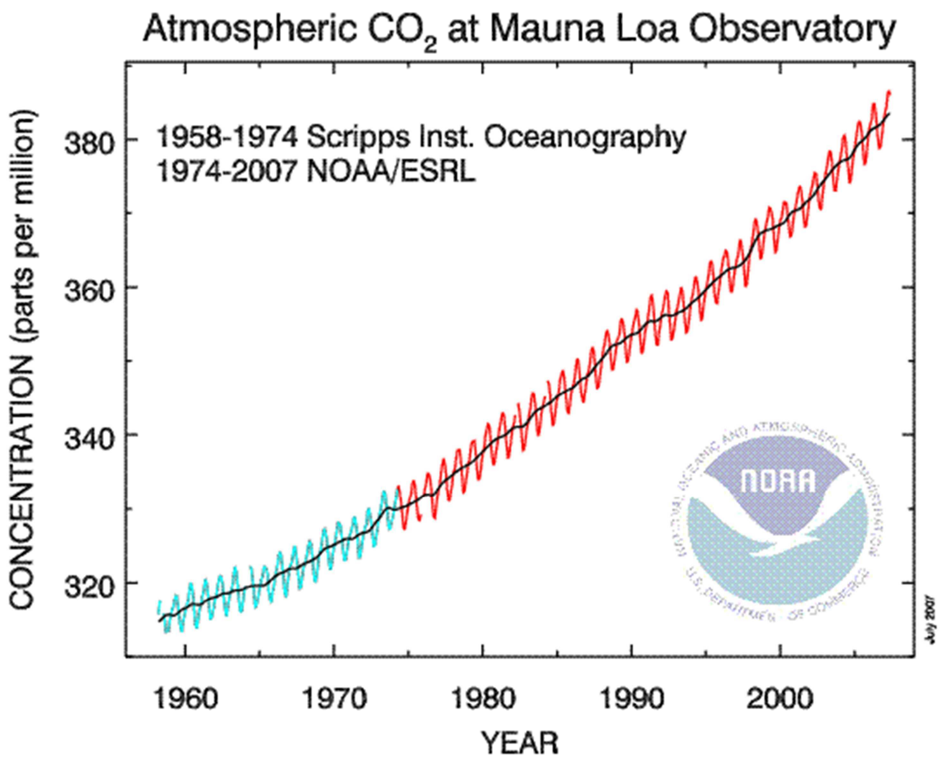

Figure 2: Atmospheric $C0_2$ concentration over the last 50 years (Keeling Curve)

Considering the final energy consumption of households / residential buildings within the EU-25 states in 2009, they have the second highest share with 27 % after the transport sector with 33 %. Services or commercial buildings are affecting the energy consumption much less but have still an appreciable share of 13 %. It follows, as shown in Figure 3, that in Europe the highest share of final energy consumption was reached in the building sector with 39 % in total.
Thus, the building sector provides great potential for energy saving measures and at the same time huge potential to reduce the greenhouse gas emissions. Hence, specific investigations on the energy demands of buildings became necessary.

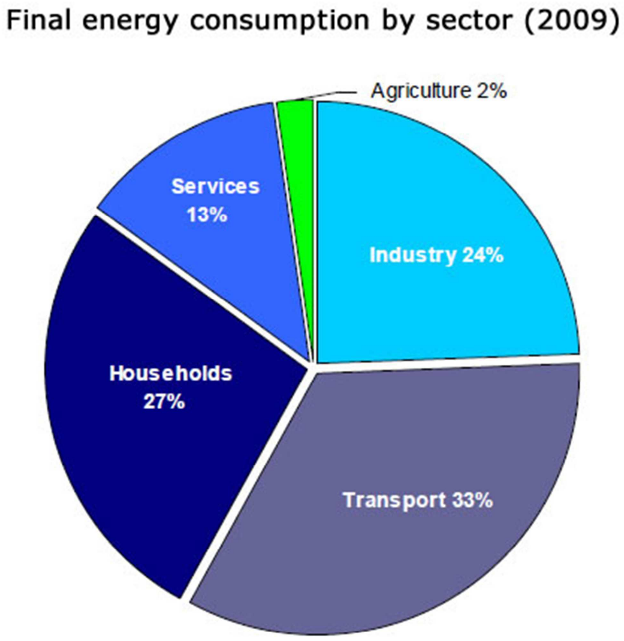

Figure 3: Final energy consumption of the EU-25 states by sector in 2009 (4)

1.2 Aim of the thesis

This report forms a part of the '**Pathways to Sustainable European Energy Systems**', which is a project with the aims of evaluating and proposing stable pathways towards a sustainable energy system that addresses environmental, technical, economic, and social issues. The focus of the project is on stationary energy systems (power and heat) in the European context. The evaluations are based on a detailed description of the present energy system and focus on how the present system could be developed within the prevailing environmental, economic, and infrastructural constraints (6).

The thesis pursued mainly three objectives: The first aim was to develop a methodology to represent the German building stock through reference buildings, that means to be as representative and accurate as possible an appropriate number of building references had to be selected. Moreover, compared to similar investigations a more detailed segmentation was established. For instance, many similar studies limited the building segmentation to two categories (type of building and year of construction - more information see chapter 2.2) while in this study also the climatic conditions (in particular the outdoor temperatures) were taken into account. Furthermore, especially the energy demand for space heating was calculated very specifically. Some input values, like the volumetric heat capacity of a building (TC-value), which describes its thermal inertia, have not been considered in other reports.
Secondly, by applying the EABS model (for more information about the EABS simulation model see chapter 3.1) analyses were made to discuss the results (= the recent energy demands in Germany) and to verify the validity of the used simulation tool.
Thus, the methodology in this invesitagtion is based on collecting input data from various sources to run the EABS model (consists of a Matlab code and simulink model) by considering also the outdoor conditions of the buildings with the help of the software Metereonorm.
Finally, by providing a representative building typology for Germany the ascertained data can be used for further investigations to determine energy efficiency measures for the German building stock.

Since not enough data about the amount and location, exact type, and year of construction of non-residential buildings are available, this report/investigation examined only residential buildings. More details why commercial or industrial buildings could not consider are mentioned in the final part of the thesis (chapter 8 Discussion and Conclusion).

1.3 Structure of the report

In chapter 2 the main sources, where most of the data were taken, are presented. Moreover, the section about the data sources depicts similar investigations of the German building stock. In addition, the current energy ordinances are illustrated which are regulating the energy efficiency of the German buildings.

Chapter 3 reports the methodology of the segmentation of the German building stock. Firstly, the EABS model, which was used for the simulation, is presented. Afterwards, the chosen criteria of the segmentation are showed and explained.

For the building characteristics (which are also representing the input values for the simulation) the extracted data from several sources are illustrated in section 4.

Chapter 5 presents the quantification of the building stock. Thereby, the quantification followed after the defined criteria which were set in chapter 3.

Chapter 6 and Chapter 7 form the most crucial sections of the thesis. In the first part of chapter 6 the results were transformed to comparable values to contrast them with values from national and international databases. In the final subsection the results are presented after the criteria of the building segmentation which are depicted in chapter 3. Chapter 7 represents the sensitivity analysis which was made for several input data/physical parameters.
The final part of the report discusses the limitations and uncertainties of the investigation.

2. Data sources

This chapter is divided into three subsections:

I. Presenting the main sources from where the data for the EABS simulation were extracted

II. Depicting similar studies for the German building stock

III. Considering the regulations and ordinances that affected the way on how to build residential houses in Germany

2.1 Sources for the extracted data

The “Institut Wohnen und Umwelt GmbH” (IWU) is a non-profit research institute of the shareholders: City of Darmstadt and the State of Hesse. The IWU has focused on research about housing, energy and integrated sustainable development. In the field of energy the IWU seeks ways to reduce the energy consumption of buildings and reducing the related greenhouse gases. Another goal of the IWU is to analyze the general conditions of buildings and to develop concepts for improvements on all levels. Furthermore, the institute collects housing data and provides geographic information services and econometrics modeling services for federal states or towns (7).

In this investigation the data for the building characterization and segmentation were mainly obtained from several sources of the IWU. The most important sources where a lot of data were extracted are presented in this section:

1) **IWU 2003**/ updated in **2005** (8) – ‘Deutsche Gebäudetypologie‘

The file ‘Deutsche Gebäudetypologie’ from 2003/2005 classified the German residential building stock after the year of construction (ten different time periods) and type of buildings (five different types of buildings) (see Figure 4).
Non-residential buildings were not considered in this publication, instead special categories for residential houses as prefabricated-houses or ‘Panelák”/”Plattenbau” were specified. Moreover, for each of the reference buildings many building characteristics were given, for instance, the heated floor area or the U-values. From this report mainly the U-values were extracted and transferred to this investigation.
A disadvantage of this publication is that the amount of buildings for each building reference remained unknown.

Figure 4: Building Segmentation form IWU 2003/2005 with Sonderfaelle (=special cases) (8)

Abscissa: The five different type of buildings (EFH=SFD, MFH=MFD [2], GMH=AP)

Ordinate: The ten different years of construction periods from buildings built before 1918 till 2005

2) **IWU 2010** (9) – 'Datenbasis Gebaeudebestand'

The aim of the investigation 'Datenbasis Gebaeudebestand' was to fill the information gaps about the German residential building sector, especially with regard to the realized energy saving measures (10).

[2] In IWU 2003/2005 GMH (**g**rosse **M**ehrfamilien**h**aeuser - English name: **A**partment **b**locks, therefore, AP) were considered as an independent category. In IWU 2011 AP and HH were merged into one single category named GMH.

Many data regarding the building characteristics of the German building stock are provided in this publication. In addition, some minor data about the distribution of the buildings were presented and were used for the determination of the building occupancy in Germany (Chapter 3.3), for instance.

3) **IWU 2011** (11)

In summer 2011 the IWU published an improved residential segmentation with the amount of buildings for the various building references, since that important information remained unknown in IWU 2003/2005. Besides, the number of segmentation criteria for the type of building was reduced (four instead of five) and simplified. So far, it is the only publicly accessible source where the amounts of buildings for the several categories/building references are presented. The reference year of the study is 2009 (as in this report), thus, many values could be overtaken directly.

Gebäudetypen*		Baualtersklassen bis 1860 A**	1861 - 1918 B**	1919 - 1948 C	1949 - 1957 D	1958 - 1968 E	1969 - 1978 F	1979 - 1983 G	1984 - 1994 H	1995 - 2001 I	2002 - 2009 J	Summe	*Anteil*
EFH		EFH_A	EFH_B	EFH_C	EFH_D	EFH_E	EFH_F	EFH_G	EFH_H	EFH_I	EFH_J		
	Wohnfläche in Mio. m²	51	155	173	127	221	213	111	148	152	114	**1.465**	*43%*
	Anzahl Wohnungen in Tsd.	510	1.370	1.720	1.240	2.150	1.930	940	1.230	1.250	880	**13.220**	*34%*
	Anzahl Wohngebäude in Tsd.	370	1.040	1.280	920	1.580	1.470	750	1.040	1.080	790	**10.320**	*57%*
RH			RH_B	RH_C	RH_D	RH_E	RH_F	RH_G	RH_H	RH_I	RH_J		
	Wohnfläche in Mio. m²		43	91	57	76	78	47	66	62	37	**557**	*16%*
	Anzahl Wohnungen in Tsd.		470	960	570	770	760	400	590	540	310	**5.370**	*14%*
	Anzahl Wohngebäude in Tsd.		350	800	480	670	650	380	540	500	300	**4.670**	*26%*
MFH		MFH_A	MFH_B	MFH_C	MFH_D	MFH_E	MFH_F	MFH_G	MFH_H	MFH_I	MFH_J		
	Wohnfläche in Mio. m²	13	112	134	131	197	109	69	76	119	41	**1.001**	*29%*
	Anzahl Wohnungen in Tsd.	170	1.490	1.920	2.000	2.800	1.500	990	1.060	1.600	510	**14.040**	*36%*
	Anzahl Wohngebäude in Tsd.	50	380	460	390	550	320	160	210	200	70	**2.790**	*15%*
GMH ***			GMH_B	GMH_C	GMH_D	GMH_E	GMH_F	GMH_G	GMH_H				
	Wohnfläche in Mio. m²		10	17	31	84	127	39	84			**392**	*11%*
	Anzahl Wohnungen in Tsd.		180	260	570	1.450	2.480	570	1.290			**6.800**	*17%*
	Anzahl Wohngebäude in Tsd.		10	10	30	60	80	30	40			**260**	*1%*
Wohnfläche in Mio. m²		**64**	**320**	**415**	**346**	**578**	**527**	**266**	**374**	**333**	**192**	**3.415**	
Anteil		*2%*	*9%*	*12%*	*10%*	*17%*	*15%*	*8%*	*11%*	*10%*	*6%*		
Anzahl Wohnungen in Tsd.		**680**	**3.510**	**4.860**	**4.380**	**7.170**	**6.670**	**2.900**	**4.170**	**3.390**	**1.700**	**39.430**	
Anteil		*2%*	*9%*	*12%*	*11%*	*18%*	*17%*	*7%*	*11%*	*9%*	*4%*		
Anzahl Wohngebäude in Tsd.		**420**	**1.780**	**2.550**	**1.820**	**2.860**	**2.520**	**1.320**	**1.830**	**1.780**	**1.160**	**18.040**	
Anteil		*2%*	*10%*	*14%*	*10%*	*16%*	*14%*	*7%*	*10%*	*10%*	*6%*		

Figure 5: Extract of the improved building segmentation from IWU 2011 with the amount of buildings for each building reference (11)

4) **TWW 2012** – www.energieberaterkurs.de

Another source where many data of the building characteristics were taken is the homepage www.energieberaterkurs.de[3] (12).
Hence, the homepage provides a free accessible conglomeration of data concerning the building characteristics. Those various characteristic values, regarding the energy balance and energetic assessment of a residential building (for instance, the hot water demand), were primarily taken from federal and state sources or from the IWU. Thus, the presented data on the homepage can be considered as highly reliable.

2.2 Similar studies for Germany

Since the German buildings stock provides one of the largest amounts of buildings in Europe, recently several similar investigations have already been conducted:

SOURCE/STUDIES	SEGMENTATION
Tabula (Typology Approach for Building Stock Energy Assessment) / www.building-typology.eu – 2009-2012 (13)	- Type of buildings - Year of construction
ARGE (Arbeitsgemeinschaft für zeitgemäßes Bauen) - 2011 (14)	- Type of buildings - Year of construction
beam^2 – Ecofys 2008 (15)	- Unknown

Table 1: Similar studies regarding the investigation of the German building stock

Tabula (Typology Approach for Building Stock Energy Assessment):
"The Tabula project aims to create harmonized structure for European building typologies. Each national typology will be a set of model residential buildings with characteristic energy related properties". (16). For Germany, IWU conducted the investigation within the Tabula project, since they have already provided the most detailed housing segmentation (see previous subsection).
The focus on the study is to show which improvements can be made to increase the energy efficiency of buildings within Germany. In that report the segmentation was made after the type of building and year of construction. Non-residential buildings

[3] www.energieberaterkurs.de is a homepage created from TWW (Trainings- und Weiterbildungszentrum Wolfenbuetel e.V.) in cooperation with the University of Applied Science Ostfalia for an off-the-job training program for engineers and architects who would like to become an energy consultant.

were not investigated. Since IWU conducted the study many data for the segmentation were taken from previous studies of the institute (IWU 2005, IWU 2011).

ARGE (Arbeitsgemeinschaft für zeitgemäßes Bauen):
The purposes for this study were almost the same as for the Tabula project. An overview of the current state of the building stock was established to get information for which type of buildings the best potential for retrofitting can be found. The segmentation was made after the type of buildings and years of construction, whereas the years of construction differ slightly from the Tabula project. Moreover, the investigation was restricted to single family dwellings, row/terrace houses and multiple family dwellings. Residential high-rise buildings and non-residential buildings were not taken into account.

beam^2 – Ecofys:
In comparison to the other studies the Ecofys investigation provides also output information about the emissions and (energy) costs. That means the focus of this study is/was to find out the role of the financial incentives and normative restrictions, as well to know what it costs to reduce the CO2 emissions caused by buildings. In this study not only residential buildings were covered but also all conditioned buildings in Germany (15).

2.3 Energy policies and regulations regarding the Germany building stock

Since 1976 there have been more than 25 legal norms in force (17):

Ordinances with currently valid legal status (17):

- **Energy Saving Act (EnEG):** Newest version from 2009. Former publications from 1976, 1980, and 2005

- **Energy Saving Ordinance (EnEV):** Actual valid status from 2009. Older versions were published in 2002, 2004, 2007.

- **Heating Cost Ordinance (HeizkostenV)** from 2008. Older ordinances are from 1981, 1984, and 1989

Archived ordinances (17):

- **Thermal Insulation Ordinance (WärmeschutzV):** Invalid – merged into EnEV. Published in 1977, 1982, and 1995

- **Heating Appliance Ordinance (HeizAnlV):** Invalid – merged into EnEV. Published in 1978, 1982, 1989, 1994, and 1998

- **Heating Plant Operation Ordinance (HeizBetrV)**: Invalid – suspended in 1989. Published in 1978

Till 1978 there was no ordinance in force which was regulating the energy saving thermal insulation of buildings in Germany. With the introduction of the **Thermal Insulation Ordinance (WärmeschutzV),** the former energy saving ordinance, the heating consumption of new buildings has been diminished massively. Thus, various other ordinances had been introduced over the time: **Heating Appliance Ordinance (HeizAnlV)** and **Heating Plant Operation Ordinance (HeizBetrV)**. The successful effect of the regulations on the energy/heating demands are illustrated in Figure 6. Hence, improved and stricter ordinances have followed:

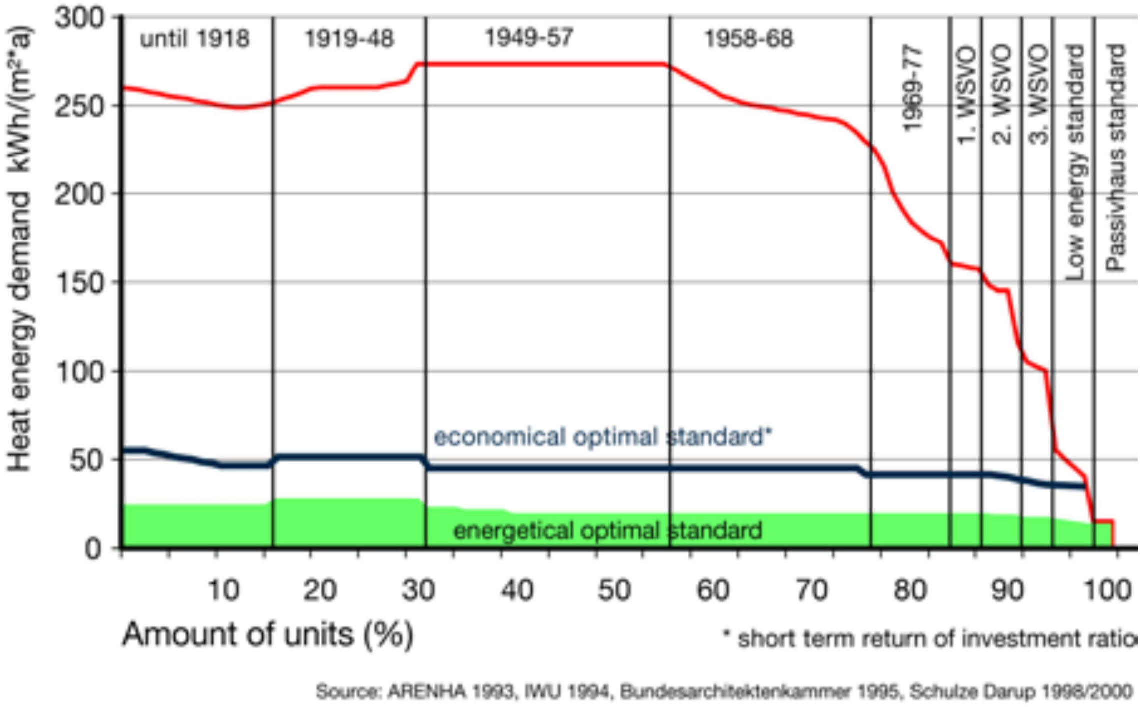

Figure 6: Since the first thermal insulation ordinance (WSVO) had been in force, the heating energy demand has been dwindling starting from 1978

Energy Saving Ordinance (EnEV): The EnEV is considered to be the current German energy saving ordinance and is an important part of the energy/climate policy of the government. The first draft was approved in 2002 and the newest version was introduced in 2009. The EnEV depicts the requirements to the primary energy demand of newly erected buildings. Thereby, the heat insulation of the building envelope as well as the energy efficiency of the systems (that means heating systems, ventilation, cooling, and lightning) are considered (18).

The EnEV 2009 also specifies that new buildings have to be issued with an *energy certificate*. *Energy certificates* serve as information about the energy consumption and energy demands of a building and are supposed to facilitate the comparison of the energy efficiency of newly erected buildings (especially with the same type of buildings) (18).

The next EnEV is announced for 2012. As the elaboration of the EnEV 2012 ordinance is still in progress not much information is present, but it is estimated that the requirements from the EnEV 2009 will be tightened to 7.5 % up to 30 % (19), (20).

Energy Saving Act (EnEG): To improve the balance of trade (in this case it means the dependency on imported energy carriers) the energy saving act was firstly introduced in 1976. The act does not contain any regulations directly affecting the citizen but empowers the Federal Government to legislate ordinances. Since the EnEG is in force many energetic requirements on buildings and their appliances have come into effect (for instance the EnEV) (18).

Heating Cost Ordinance (HeizkostenV): The ordinance regulates the allocation of heating and warm water costs in centrally supplied buildings. The ordinance is supposed to encourage the user to save energy, since a mayor part of the billed costs of the metered consumption has to depend on the consumption of the user (18). The first version was issued in 1981 while the current one was released in 2008.

3. Methodology of segmentation of the German residential building stock

3.1 The EABS model and structure of the investigation

The model used to perform the energy simulation in this thesis is the Energy Assessment of Building stocks (EABS), which was developed within the Pathways Project. This modeling approach is based on the calculation of the energy demand of a group of buildings that are described in detail and selected to be representative of the entire stock. By scaling-up the results reasonable statements for a particular region can be made (bottom-up model) (21).

Figure 7 illustrates the bottom-up model and the structure followed to develop this thesis. Thereby, the structure and development is similar to other investigations concerning the Pathway Projects for characterizing the national building stock (for instance, for Spain (21), and France (22)):
Firstly, the segmentation had to be established where the definition and the number of the archetype buildings were designated. Secondly, the archetype buildings had to be characterized (i.e. technical characteristics) while the third step was the quantification of the archetype buildings. The three steps are depicted in detail in the following chapters:

Segmentation: Chapter 3.2

Characterization: Chapter 4

Quantification: Chapter 5

With the segmentation, characterization, and quantification all precautionary measures were made to apply the EABS model:
The EABS model consists of two parts: A Simulink model, which solves the energy balance for buildings, and a code written in Matlab, which handles the input and output data from the Simulink model. The output data (=net energy demand of the reference buildings) is obtained based on the physical and thermal properties of the buildings, a description of the heating systems, ventilation systems and building and climate conditions (input data) (23). The list of the input data for the EABS model is presented in the next chapter (Table 9: Input data for the EABS model), since one of the main tasks for this investigation was to collect those input data to run the EABS model successfully. More information about the Matlab code which was used in this report and the EABS model in general can be found in (23).

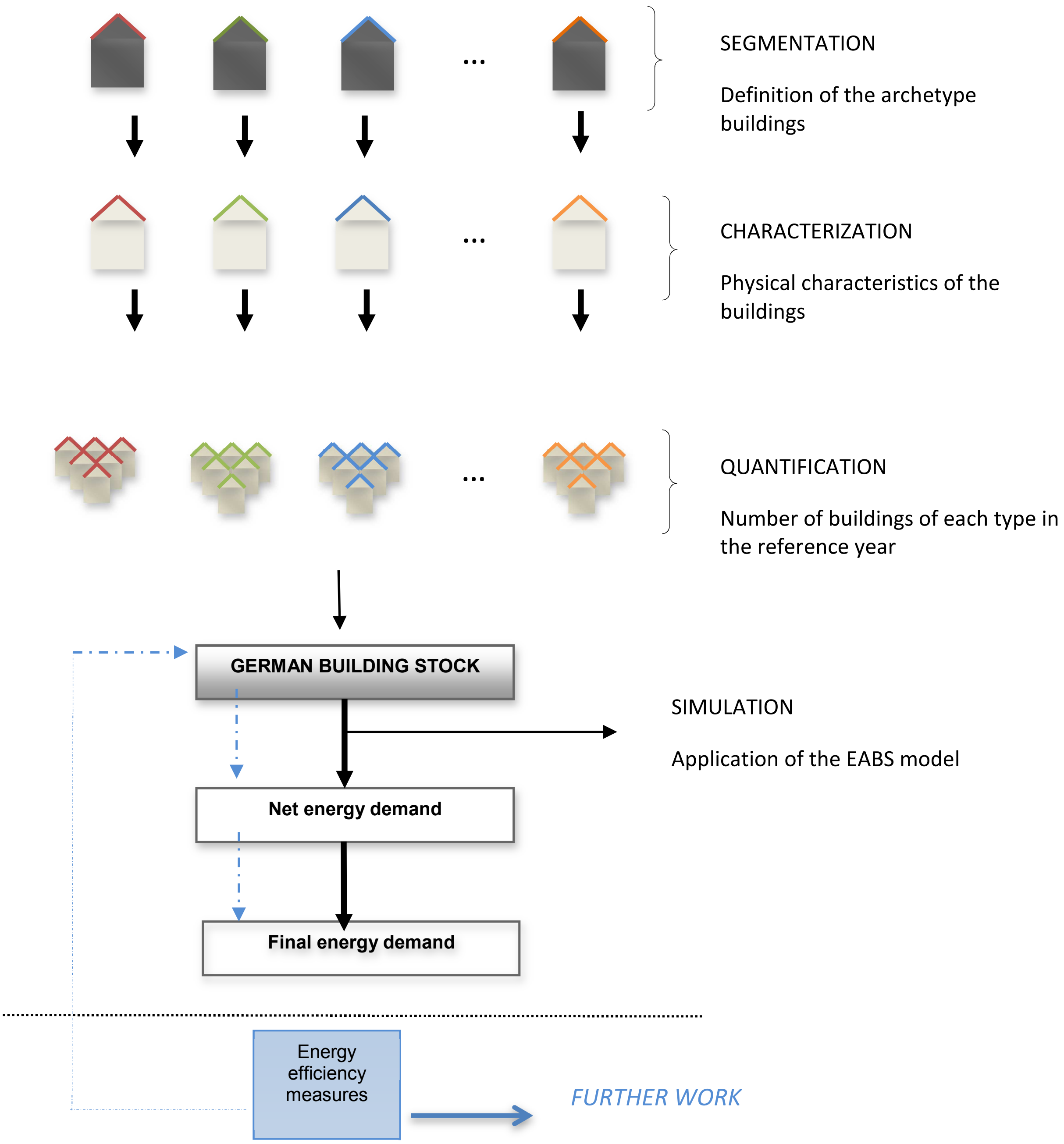

Figure 7: Methodology based on a bottom-up approach to describe the building stock through archetype buildings, used in this master thesis.

Finally, the results (= output data) of the energy simulation are compared to data available in several national and international databases expressed in terms of final energy demands. To obtain comparable results the net energy demand for end-uses was converted into final energy demand, using assumptions on efficiencies for the different fuel shares (see chapter 6).

3.2 Segmentation of the building stock

To establish an accurate German building typology several information and data had to be taken into account. In former research projects a building typology after architectural segmentation criteria was in common (Table 1).
Hence, in this report the building references are also defined by their architectural scales: Type of dwellings (a) and year of construction (b). As stated in the introduction, one reason why this thesis distinguishes form former similar report is the more specific segmentation. Therefore, the segmentation was also extended by a third category: The location of buildings associated with the climate zones (c). Furthermore, other minor criteria that have an impact on the energy consumption (for instance the occupancy of buildings) are not listed separately as an independent category but are also considered in this report and are integrated within the three main criteria.

(a) Type of building

A classification after the types of buildings facilitates to get information about the size of buildings which has, for instance, an impact on the values of the effective heat capacity (TC). Besides, buildings of the same size usually have similar energy demands. Thus, the classification of buildings is a useful parameter and plays a crucial role for the simulation of the EABS model since it also affects many other input data within the simulation. Table 2 gives an overview over the affected values.

Notation	Description
TC	Effective heat capacity of the building
$\mathbf{Tr_{min}}$	Minimum desired indoor temperature
$\mathbf{Tr_{max}}$	Maximum desired indoor temperature
$\mathbf{O_c}$	Specific heat gain from people
$\mathbf{L_c}$	Specific heat gain form electric lights
$\mathbf{A_c}$	Specific heat gain from appliances
A	Heated floor area
S	Total exterior area of a building envelope
$\mathbf{V_c}$	Sanitary ventilation rate

Table 2: Input values which are affected by the type of building

In existing literatures several building typologies for the German residential stock are available (see previous chapter). Similar investigations, mainly just considered single-family dwellings (SFD) and multi-family dwellings (MFD) - up to 12 apartments (for instance, ARGE (14)).

In this report five different building types were derived from IWU 2005, since the building classifications from that source is very accurate and representing the German residential stock very well.

The IWU (IWU 2005) divided the buildings into the following categories: SFD, RH MFD, AP and HH:

SFD/TFD: Single-family dwelling / Two-family dwelling also prefabricated houses

Figure 8: Typical SFD in Germany (8)

RH: Row house with several one accommodation units in a row.

Figure 9: Typical RH in Germany (8)

MFD: Multi-family dwelling with maximal four floors and eight till ten apartments on average.

Figure 10: Typical MFD in Germany (8)

AP: Apartment block with maximal ten floors.

Figure 11: Typical AP in Germany (8)

HH: High Tower / High-rise buildings consisting of more than ten floors, mostly "Panelák"/"Plattenbau" constructions from the 1960s and 1970s

Figure 12: Typical HH in Germany (8)

After IWU a **SFD** can be a single-family dwelling or a two-family dwelling. The same applies for **RH**s. Furthermore, prefabricated buildings (German:"Fertighaus") were also considered in the building typology of IWU and are categorized in this investigation, for reasons of simplifications, as SFDs.

A **MFD** is considered not to have more than 12 but at least three apartments per building.

APs are multi-family dwellings with more than 12 apartments per building and the building itself has not more than 10 floors.

A **HH** building consists of a minimum of 13 apartments and has at least 10 floors.

To fulfill the housing demands in the former German Democratic Republic, many "Plattenbausiedlungen/ Panelek" (large-panel system building) were built during the 1960s and 1970s. After IWU 2005 the classes NBL_F till NBL_H and HH_F are mainly classified as large-panel buildings ("Plattenbausiedlungen/ Panelek") (see Figure 4). For simplification, IWU 2011 assigned those buildings, together with APs and HHs, into one category (GMH, see figure 5). To receive more accurate results and since the segmentation of type of buildings is based on IWU 2005 the AP and HHs remained in this report two separate categories. Thus, one category more was considered compared to IWU 2011.

(b) Year of Construction

The second important category to determine the buildings is the age of construction. Since over the time the technological developments in construction technology were getting more sophisticated and the significance for energy saving was getting more important, it can be assumed that older buildings consume more energy than newer buildings (24). Thus, it is evident that there is a strong correlation between the energy consumption and the year of construction.
Due to the Second World War and many other historic events the majority of the existing buildings were built after 1949. But, especially in the rural areas, many houses were untroubled by the wars, hence, a lot of buildings which were constructed in the beginning of the 20th century or earlier can still be found in Germany.
Besides, the various construction types (for instance, Bauhaus[4] in the 1920s) influenced the way how the buildings were erected.
Furthermore, the thermal insulation ordinance („Waermeschutzverodnung"), firstly introduced in 1978 and renewed in 1985, and 1996, and later replaced by the stricter EnEV („Energieeinsparverordnung") in 2002, which was moderately renewed in 2007, and 2009 also affected massively the way of building houses in Germany.

[4] Bauhaus is an architectural style with fine arts elements developed in Dessau (Germany) and was used for many buildings which were erected from 1919 till 1933.

It is estimated that a building, constructed after such a regulation has been published, complies with the new rules (24).

In a nutshell: The year of construction affected the construction of residential buildings (i.e. the input values) in three vital forms:

1. Historical events: World Wars (material shortage), framework houses built mainly in the center of the city etc.

2. Construction types: Preindustrial construction methods, introduction of new styles (like Bauhaus) etc.

3. Introduction of Regulations: First thermal insulation ordinance (limiting U-values for windows, walls etc.), introduction of the EnEV etc.

These three categories lead to the following classification of the year of constructions which is depicted in Table 3:

Period of construction	Description (25), (26)
Till 1918 all buildings except framework	- Partially preindustrial construction methods - otherwise steel is the dominate material
Till 1918 only framework buildings	- mostly timber framwork facades - often located in historic districts of the town - special efforts necessary to fulfill modern heat protection standards
1919 – 1948	- built after the first World War - Bauhaus style and expressionism - introduction of cavity walls
1949 – 1957	- built after the second World War - shortage of material
1958 – 1968	- DIN 4108 „Waermeschutz im Hochbau
1969 – 1979	- Extension of DIN 4108
1979 – 1983	- First thermal Insulation ordinance
1984 – 1994	- Second thermal Insulation ordinance
1995 – 2001	- Third thermal Insulation ordinance
2002 – 2009	- EnEV

Table 3: Year of construction for the German residential building stock

Concerning Table 3 the introduction of regulations have started playing a crucial role from 1979, while some minor regulations were already released in the 1950s and 1960s. Historical events and the type of construction had been prevalent reasons how to erect buildings till the 1950s.

(c) Climate Zones

Another building characteristic correlated with the energy consumption is the climate zones where the buildings are located.

The outdoor temperatures have a significant impact on the heating and cooling demand of a building. Compared to the Mediterranean climate of Italy or Spain cooling can be neglected in a moderate climate zone (like German climate) because the average maximum temperature in summer is mostly less than 25 °C. Furthermore, not many buildings (especially the older ones) are equipped with a cooling system. Thus, in Germany cooling is only necessary if the building is not designed “correctly” or if the tolerance of the occupants to warm temperatures is low (27).

But due to cold average winter/autumn temperatures the heating demands have to be considered, moreover, the heating consumptions have the highest share for the total energy demand of a building. In Germany the heating border (“Heizungsgrenze”) regulates the outside temperature at which the heating system of an occupied dwelling house must work. In the current EnEV the “Heizungsgrenze” is given with 12-15 °C. That indicates that the heating period in Germany is from the first of October till the end of April (7 months).

As illustrated in Figure 13 Germany is divided into four temperature/climate zones. The depicted temperature zone segmentation is also the basis for calculating the heating load after the DIN EN 12831[5]. This climate classification is based on the lowest air temperatures within two consecutive days which were reached ten times within a time period of 20 years.

[5] The calculation method for the heating load is specified in the norm DIN EN 12831. It says how much heat has to be supplied to reach the desired indoor temperature.

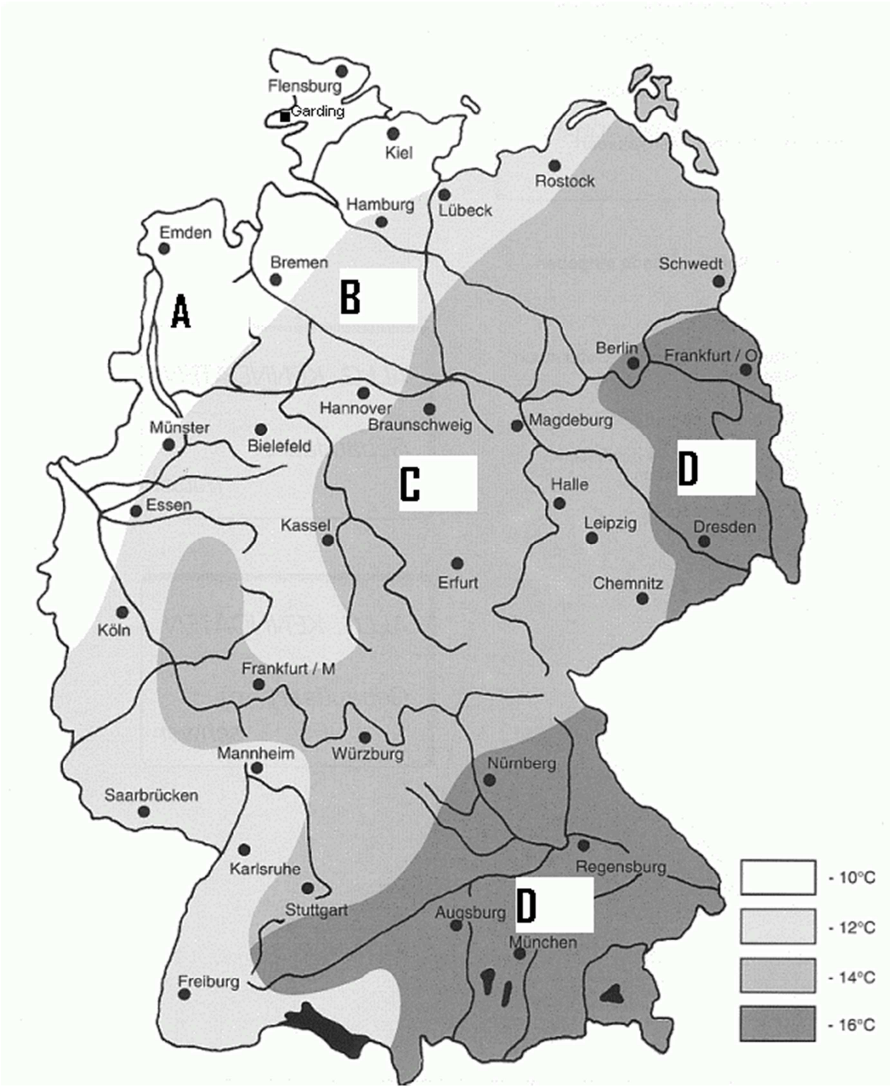

Figure 13: Winter Climate zones in Germany (28).

In the literature there was no information available on how many residential buildings can be found in the several climate areas. To keep the weather zone methodology as simple as possible and run the simulation at the same time with reasonable values, a few assumptions and simplifications were made to determine the final amount of buildings in the different zones.

Firstly, the A and B zones (from Figure 13) were merged into a bigger, single zone. The weather pattern of both climate zones are similar, furthermore, the -10 °C zone mainly covers the coastal area where, relatively speaking, not many dwellings are located. Thus, a fourth climate zone would make the model a bit more abstract but no significant changes in the results would occur.

Secondly, the population in every German state ("Bundesland") to the population in entire country is considered to be equal to the number of buildings in every state to the number of buildings nationwide. For instance, 15% of the total German

population is living in Bavaria. Thus, the share of the residential building stock in Bavaria is assumed to be also 15 %.
The amounts of houses for three different regions are known (North, East, and South Germany) (9), the same for the population in the 16 states. By combining and calculating with those and other values (for details see Appendix 1) it is possible to obtain the amount of buildings for each German state.

Thirdly, each of the 16 states has to be determined to one of the three climate zones. The determination was carried out with the help of Figure 14: Map of Germany with the 16 states and Figure 14: Map of Germany with the 16 states From these figures it can be seen that, for instance, the area of Schleswig-Holstein clearly can be determined to zone A (as stated previously, the climate zones A/B were merged into one zone A). It follows, that the states Schleswig-Holstein, Hamburg, Lower Saxony, North Rhine-Westphalia, Saarland, and Bremen also belong to Zone A. Larger parts of Hesse partly lie in two different zones (see Figure 13 and Figure 14), for simplification Hesse was determined to zone A. The accomplished determination of the 16 states is listed in Table 4 and illustrated in Figure 15. Thus, the borders of the three climate zones are going along the borders of the states and are not separated by their 'meteorological frontier'. The climate zones for the French building stock are divided into similar patterns (see (22)).

Figure 14: Map of Germany with the 16 states (29)

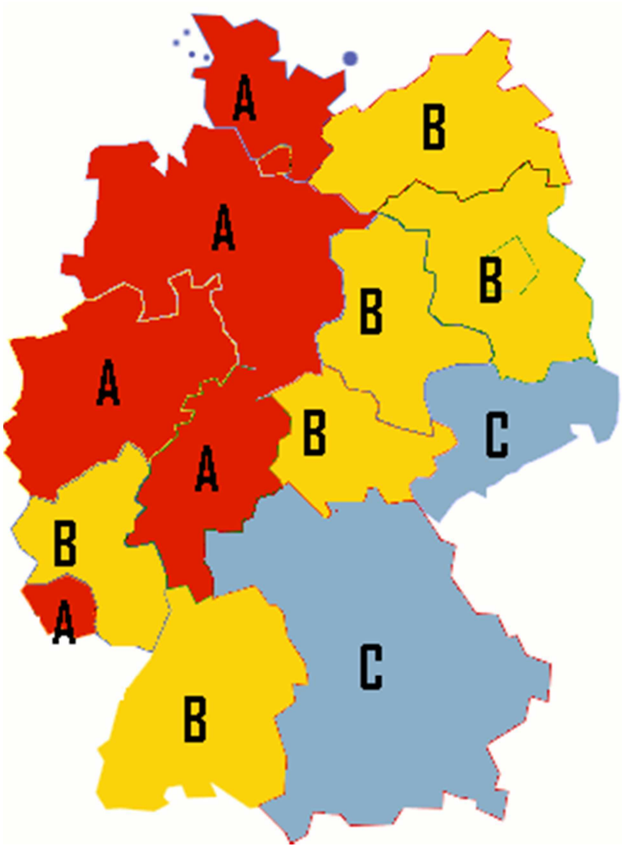

Figure 15: The 16 German states (Bundeslaender) determined to one of the three climate zones

A	B	C
Bremen	Baden-Wuerttemberg	Baveria (Bayern)
Hamburg	Berlin	Saxony (Sachsen)
Hesse (Hessen)	Brandenburg	
Lower Saxony (Niedersachsen)	Mecklenburg-Vorpommern	
North Rhine-Westphalia (Nordrhein-Westfalen)	Rhineland-Palatinate (Rheinland-Pfalz)	
Saarland	Saxony-Anhalt (Sachsen-Anhalt)	
Schleswig-Holstein	Thuringia (Thüringen)	

Table 4: The 16 German states (Bundeslaender) determined to one of the three climate zones

Since the EABS simulation is running only with one weather file (from Meteonorm) for each climate zone (that also means with only one reference city per climate zone), the mean temperature for the several climate areas had to be calculated:
The used version of Meteonorm mostly provided two or three reference cities per state (exception: No data were available for Saxony-Anhalt). In those cases usually the biggest city was chosen to get the best accuracy and be as representative as possible. An overview with the chosen reference cities for each state is provided in Table 5:

Climate zone	Region	Reference city	Annual mean temperature (°C)	Mean value for climate zone (°C)
A	S.Holstein+Hamburg	Hamburg	8.70	9.49
	Lower Saxony+Bremen	Bremen	9.17	
	North Rhine Westp.	Essen	9.61	
	Hesse	Frankfurt	10.66	
	Saarland	Saarbruecken	9.31	
B	Baden-Wuerttemberg	Stuttgart	8.99	8.74
	Rhineland-Palatinate	Trier	9.15	
	Thuringia	Coburg	8.07	
	Brandenburg+Berlin	Berlin	9.04	
	Saxony-Anhalt	-	-	
	Mecklenburg-Vorpommern	Rostock	8.47	
C	Baveria	Nuremberg	8.77	7.41
	Saxony	Dresden	6.02	

Table 5: Reference cities and calculated mean temperature for each climate zone

Finally, with the values from the reference cities the mean temperature for each climate zone could be ascertained and the city which is the closest to the mean value could be determined as the reference city for the simulation: For instance, for zone A an average value of 9.49 centigrade was carried out (see Table 5). That implies that the chosen reference city/weather file for zone A and also for the simulation is Essen, since it is with 9.61 °C very close to the mean value. Thus, Stuttgart was obtained for zone B and Munich for Zone C (since the deviation for Dresden and Nuremberg was too high from the mean value) (Table 6):

Climate zone	Mean value for climate zone (°C)	Chosen city, weather file
A	9.49	**Essen with 9.61°C**
B	8.74	**Stuttgart with 8.99°C**
C	7.41	**Munich with 7.73 °C**

Table 6: Chosen weather file for the simulation for each climate zone

3.3 Building occupancy

By running the EABS model with the three categories stated above, chapter 3.2 (a), (b), and (c), moderate-high deviations for the output values were observed compared to the output data of other national and international databases (see also chapter 8). At first, it was assumed that all residential buildings were occupied. But because of the great impact of the building occupancy on the energy consumption the unoccupied houses had to be excluded, since their energy consumption is very low and unpredictable (30). Therefore, a minor segmentation category, the building occupancy, had to be added to obtain consistent and reasonable output values.
In 2009 in West Germany 3 % and in East Germany 9.9 % of all residential buildings remained unoccupied (31). Moreover, from IWU 2010 (9) it was obtained that in 2009 82.4 % of the residential buildings were located in West Germany and 17.6 % in East Germany. It follows:

The share of occupied buildings in West/East Germany:

East: 100 % - 9.9 % = 90.1 %
West: 100 % - 3 % = 97 %

Location	Share of buildings	Total amount of buildings	Share of occupied buildings	Amount of occupied buildings
West Germany	82.40%	14,864,960	0.97	14,419,011
East Germany	17.60%	3,175,040	0.901	2,860,711
Germany	**100 %**	**18,040,000**		**17,279,722**

Table 7: Building occupancy in Germany

➔ Unoccupied residential buildings in Germany (mean value):

$$\frac{(18{,}040{,}000 - 17{,}279{,}722) * 100}{18{,}040{,}000} = \mathbf{4.24}\ \%$$

Thus, it was assumed that each of the 122 reference building has an average occupancy of 95.76 %.

3.4 Amount of Reference buildings

An overview of the 122 reference buildings is given in Table 8 and in detail presented in Appendix 2.

Type of Building	SFD RH MFD AP HH
Year of Construction	till 1918 till 1918 framework 1919-1948 1949-1957 1958-1968 1969-1979 1979-1983 1984-1994 1995-2001 2002-2009
Climate Zones	A B C
Reference Buildings	**122**

Table 8: Amount of reference buildings

4. Characterization

To get a reliable value of the energy demand of the German residential stock and to fulfill one of the main purposes as stated in chapter 3.1 the input value had to be gathered to run the EABS model successfully. In general these parameters are referred to the building geometry, the properties of construction materials, required indoor climate conditions or to the thermal characteristics of the building service systems (23). An overview of the needed values is depicted in Table 9 and commented and explained in this chapter.

Notation	Description	Units
TC	Effective heat capacity of the building	J/K
W_c	Solar shading coefficient for a window	0-1
W_f	Part of the total window area covered by window frames	0-1
T0	Initial indoor temperature	C
Tr_{min}	Minimum desired indoor temperature	C
Tr_{max}	Maximum desired indoor temperature	C
S_h	Maximum heating power of a heating system	W
S_c	Maximum cooling power of a cooling system	W
P_h	Response capacity of a heating system	W/K
P_c	Response capacity of a cooling system	W/K
HRec_eff	Efficiency of the heat recovery unit	0-1
Pfh	Specific heat gain from ventilation fans	W/ m^2
T_v	Set point temperature for natural ventilation	C
O_c	Specific heat gain from people	W/ m^2
A_c	Specific heat gain from appliances	W/ m^2
L_c	Specific heat gain form electric lights	W/ m^2
V_{cn}	Natural ventilation rate	l/s/ m^2
V_c	Sanitary ventilation rate	l/s/ m^2
HyP	Specific electric power demand for operation of hydronic pumps	W
COP	Coefficient of performance of heat pumps	-
Weight	Coefficient to scale up the type to the whole building stock	-
T_s	Window solar transmittance	0-1
A	Heated floor area	m^2
S_w	Total window area	m^2
S	Total exterior area of a building envelope	m^2
SFP	Specific fan power	W/l/ m^2
H_w	Specific heating power demand for hot water production	W/ m^2
U	Heat transfer coefficient of the building	W/m^2K

Table 9: Input data for the EABS model

Heated Floor area (A)

In IWU 2005 the heated floor area for all the 122 references buildings is given in W/m^2. Since the amount of buildings (thus, also the living space in m^2) had been changing within four years (because our reference year is 2009), the values could not directly transfer to the EABS model but had to be modified.
According to IWU 2009 the heated floor area for the entire country is 3.415*10^9 m^2. Moreover, for almost every building reference the living space (in m^2) and the amount of buildings are given. Thus, the heated floor area for many types of buildings can be calculated by dividing the amount of dwellings by the living space:

$$A_i = \frac{Total\ living\ space\ of\ each\ building\ reference\ [in\ Mio\ m^2]}{Total\ amount\ of\ each\ building\ reference}$$

For some AP and HH building references, the arithmetic average of GMH_F till GMH_H from IWU 2009 (see figure 5) was determined and finally equally distributed to the used segmentation of the thesis.
An overview about the acquired heated floor area is shown in Appendix 3.

The heated floor area is required for almost all the other parameters:

- Ventilation losses
- Heat gains
- TC-value
- Demand of hot water

Other surface areas (S, S_w, S_{floor}, S_{roof}, S_{wall})

Compared to former Pathway investigation (for example, France (30), or Spain, (21)) the several areas for the each building reference could be easily extract from the literature (IWU 2005 and IWU 2009) and no (extra) calculations had to be made.

Minimum desired indoor temperature (T_{rmin})

In Germany the typical range for indoor temperature of residential buildings are from 18 °C up to 22 °C (32). In the literature or for other investigations mostly 20°C is set as the desired indoor temperature. Indoor temperatures lower than 18 °C are considered as uncomfortable by occupants.
In former and similar Pathway investigations (for instance, about the Spanish building stock) 18°C was set as the minimum desired indoor temperature.
In addition, the indoor temperature is for for each room different. While in comfort areas like in the living room the temperature is set mostly higher than 18 °C for all the other rooms (like bathroom and floor) lower temperatures occur. Furthermore, most

of the dwellings remain unheated while the occupants are at work during the daytime in the winter period.
The reasons mentioned above are all reasons why for Germany **18°C** (T_{rmin}) is assumed for all 122 building references.

Besides, the indoor temperatures are varying a lot over the year. During the summer inside temperatures of over 24 ° can be reached. Furthermore, from November till the middle of February the average indoor temperature is around 20 °C (32). Since no detailed information were available and to keep the simulation as accurate and at the same time as simple as possible the T_{rmin} was assumed to be constant with 18°C over the entire year.

Heat Use:

Specific heating power demand for hot water production (H_w)

Heating power for hot water has with around 9 % the second highest share of final energy demand after space heating with 80 % (see **Error! Reference source not found.**). The H_w-value is not related to the house size, but rather to the number of persons living in a household. Nonetheless, the 'EnEV' suggest a general energy demand of 12.5 kWh /m²a. Compared to the space heating the potential for energy saving within this area has more to do with the type of usage than with technical improvements (24).

The specific hot water demand could directly extract from TWW (33):

SFD = 10.2 kWh /m²a

RH = 11.7 kWh /m²a

MFD = 21.6 kWh /m²a

AP = 29.6 kWh /m²a

HH = 29 kWh /m²a

For the simulation used in this report these values have to be changed into W/m^2:

A year has 8765h: 1000 Wh / 8765 m^{2}h = 0.11409 W/m^2. For requiring the desired values in W/m^2 multiply 0.11409 W/m^2 with the value above for every type of dwelling. Results see in the table below:

SFD	= 1.16 W/m^2
RH	= 1.33 W/m^2
MFD	= 2.46 W/m^2

AP	= 3.38 W/m^2
HH	= 3.31 W/m^2

Table 10: The specific heating demand for hot water

<u>TC-Value: Effective internal heat capacity of the building (TC)</u>

The effective heat capacity of a building, also known as thermal mass, characterizes how the mass of a building provides 'inertia' against temperature fluctuations. It is determined by summing the volumetric heat capacities of the layers in direct contact with the internal air (23). Thus, the exterior walls, internal walls, and middle floors are added up and are calculated as followed:

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i$$

ρ_i is the density of the layer (kg/m3)

Cp_i is the specific heat capacity of the layer (J/kgK)

S_i is the area of the layer (m3)

d_i is the thickness of the layer (m).

Three steps had to be done to obtain the TC values for the 122 reference buildings (the entire and detailed calculations are presented in Appendix 4):

I. Determine Cp_i ,ρ_i and the building components

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i$$

To obtain the density ρ_i and specific heat capacity Cp_i of the layers, the construction materials within the different classes of year of construction have to be identified. It is not necessary to differ also in the various types of buildings since all housing types within a building period are mostly established with the same components. That means for instance that for SF, RH, MFD, AP, and HH, erected in the same time interval, equivalent materials were used. Sources which were applied in this master-thesis to find information for used materials in German houses are: Dortmund (source not online anymore. 08.2012), KQB (26), and Bayern (IWU) (34).

Afterwards, the density and the specific heat capacity, which are related to the used materials, could be easily found out with the help of tables and formularies from the internet. Source: (www.schweizer-fn.de).

II. Determine d_i :

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i$$

According to EN ISO 13790, the maximum thickness is 10 cm or the middle of the building element, whichever comes first. In Germany all buildings consist of layers which are at least 10 cm thick, but depending on their year of construction having several/different materials within those 10 cm. In Appendix 4 the used materials and the thickness for each material are represented.

III. Determine TC/S_i :

$$\frac{TC}{S_i} = \sum \rho_i \cdot Cp_i \cdot d_i$$

To finally acquire the TC values, firstly the TC/S_i has to be calculated. In the first two steps the specific heat capacity, the thickness of the layers, and the density were determined. Thus, we can ascertain the TC/S_i values easily for each building reference by multiplying and summing up the three parameters (see also Appendix 4).

Finally, the size (area) S_i for the ceiling, floor, exterior and interior wall has to be found out. For simplification, the assumption was made that all floor areas are equal with the sizes of the ceilings. The values for the ceiling and floor areas could be obtained from various sources (for instance, IWU). The same applies for the sizes of the exterior walls.

Due to the lack of information regarding the interior walls further investigations had to be made. Hence, several ground plans of houses in Germany (35) had to be analyzed. From those ground plans the measurements of the interior walls could be determined. Thereby, the average thickness of an interior wall is 17.5 cm (i.e. 8.75 cm for each side of an interior wall) Since, after EN ISO 13790, the maximal thickness is limited to 10 cm only 87.5 % of the size has to be considered. To avoid any complications and for simplification in the EABS model the ratio of 0.875 was applied to all type of buildings. Thus, to require the TC-value for each type of building the floor, wall, and ceilings areas have to be multiplied by 0.875 and the demanded thermal mass (TC) value could be calculated.

Transmission heat losses

The transmission heat losses are defined as:

$$q_t(t) = U * S\,[T_{out}\,(t) - T_{int}\,(t)]$$

(a) U-value

The U-value or U-factor is the average thermal transmittance of a building envelope, or in other words: It is the rate of doors, windows, floors, walls, and roofs on how much heat losses they allow (23).

U-values play a significant role if it comes to the energy efficiency of a building (!). Thus, the lower the U-value the better is the insulation for a house with the same surface size. Due to the introduction of the 'EnEV' or 'Warmeschutzverdnung' the U-values for newly erected buildings are regulated (see also chapter 2).

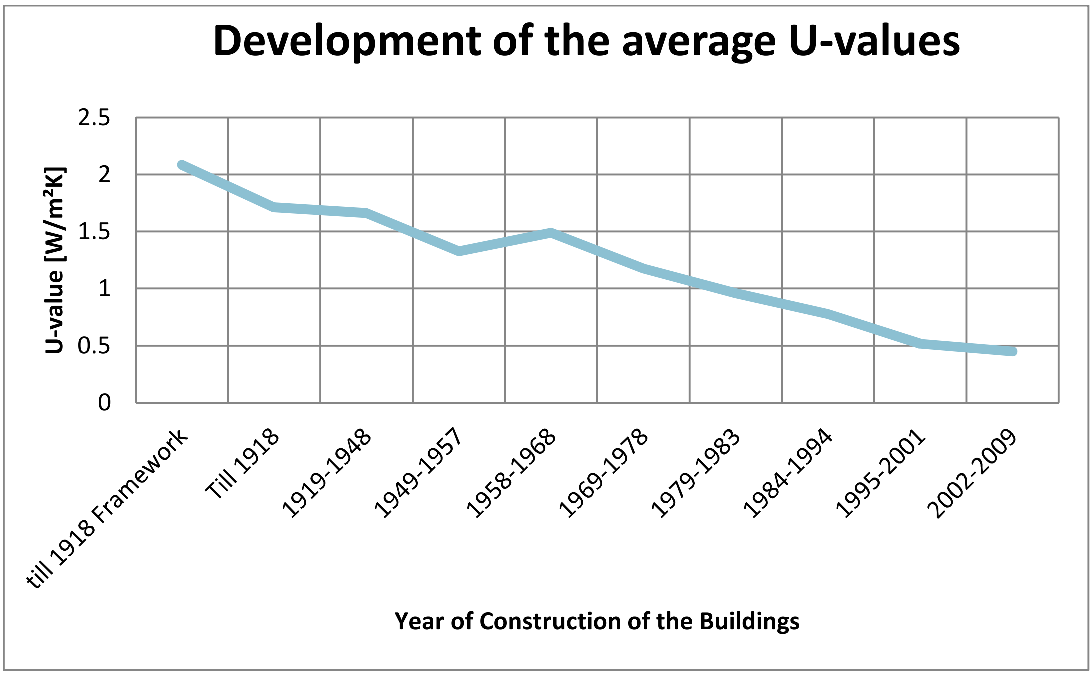

Figure 16: Development of the U-values in Germany over the last hundred year

Nowadays, there are still many old buildings with an average U-value up to 2.37 (see IWU 2005). On the other side, modern buildings have an average U-factor of 0.45 (see IWU 2005). Regarding the U-values, especially row houses, that had been built from 2002-2009, are showing an exceptional performances. Their final average U-value is only 0.42 what is the lowest mean value among all the other building references (IWU 2005).

The final U-values for each building reference are calculated by the area weighted of the single U-values (of the windows, doors, roofs, and walls). That means that the final U-value for each building reference is determined from the amount of the single U-values multiplied with the related surface areas divided by the total area:

$$U_i = \frac{U_{wind,i} * S_{wind,i} + U_{wall,i} * S_{wall,i} + U_{roof,i} * S_{roof,i} + U_{floor,i} * S_{floor,i}}{S_{total}}$$

For the EBAS model all the following single U-values ($U_{wind,i}$ $U_{roof,i}$, $U_{floor,i}$, $and\ U_{wall,i}$) and surface areas ($S_{wind,i}$ $S_{roof,i}$, $S_{floor,i}$, $and\ S_{wall,i}$) for each building reference were taken from IWU 2005:

1) <u>Used U-values</u>

I. Windows: (U-values from 1.6 till 5.2)

Since windows are transparent, they disclose much larger heat losses than walls or doors. Therefore, they have by far the highest U-values. The range starts from 1.6 for windows in newer buildings and goes up to 5.2 for windows in apartment block buildings from Eastern Germany.

II. Walls: (U-values from 0.24 till 1.9)

The U-values are much lower than for windows. We get the highest U-value for walls in framework buildings that were built before 1918. The lowest U-values can be found in row houses that have been built after 2002.

III. Floor: (U-values from 0.29 till 1.65)

The range of the floor U-values is similar to the U-values of the walls. After IWU 2005 row houses that had been built between the two World Wars have the least insulation levels. Those dwellings can reach values up to 1.65. Conversely, row houses which have been built from 2002 have the best performance with 0.29.

IV. Roof: (U-values from 0.21 till 2.6)

Especially very old buildings with several stories (MFDs or APs erected before 1918) consist of roofs with high U-values. A very good value with 0.21 is reached by row houses which were built in the last decade.

2) <u>Used surface area</u>

Windows: IWU divided the windows into windows with North, South, and East/West direction. The window surface area is calculated by the amount of the window surface area in all four directions.

Walls and Roofs: In IWU 2005 the external surface area for each building reference is listed. Therefore, the values could take over directly.

Floor: Only the lowest floor surface area has to be considered because the lowest floor is in direct contact with the surroundings/earth and transfers the heat out of the building. These values could be also taken over directly from IWU 2005.

Ventilation heat losses

(a) *Natural ventilation rate (V_{cn}) and set point temperature for natural ventilation (T_v)*

The natural ventilation is a system that does not require (external) energy, thus it does not influence directly the energy consumption of a building (30). It has to be concerned if, for instance, an occupant opens the window and air flows into the buildings.
Thus, we have to take the natural ventilation rate into account when we are passing a particular room temperature (the set point temperature) or when we do not have comfortable air conditions (heat recovery systems) for the occupants of a building (see next subsection).
This *set point temperature for natural ventilation (T_v)* is the temperature when we can assume that people would open the windows to refresh the air or for cooling down the room temperature in the summer.
During the summer months occupants tend to open the windows completely to replace the air and cool down the room temperature. Moreover, a window also could be opened partway or tilted. For simplification, the assumption was made that only a fully open window is used for the natural ventilation. Therefore, we get from VDB a rate of **8.8 1/h** for completely opened windows what means that the whole air in the room will be substitute 8.8 times within an hour (36).

The value of **24°C** for the set point temperature was taken from the investigation about the Spanish building stock which was also a Pathway project (21). That means if the indoor temperature passes 24°C the residents will open the windows for cooling. Thus, the need for natural ventilation occurs normally in summer (23).

(b) Sanitary ventilation rate (V_c)

The sanitary ventilation rate is the minimum ventilation flow rate in buildings or the necessary airflow rate for ventilation to have the desire indoor air quality (23).

Thereby, we differ in ventilation systems with and without heat recovery. In Germany the share of buildings with a mechanical ventilation system is less than 1.5 % and only around half of them are coming with heat recovery. Additionally, 10 % of the newly constructed buildings are equipped with a ventilation system (9). Due to the small amount of buildings with ventilation systems including heat recovery, in this report only systems without heat recovery were considered. Hence, to determine the sanitary ventilation rate the natural ventilation rate has to be considered (see formula below) since in Germany the airflow is mostly regulated 'naturally' and not with a heat recovery system.

The V_c-values were obtained TWW 2012 (37). According to TWW 2012 the change of air ventilation without heat recovery is calculated as followed:

$$n = n_{nat} + \Delta n$$

Where n_{nat} is the natural ventilation rate during the usage period and Δn is the difference ventilation rate.

The applied values in this Master-thesis are (37):

0.6+0.25	=**0,85**[1/h]	for buildings older than 1979
0.6+0.15	=**0,75** [1/h]	for buildings built between 1979-1994
0.6+0.0	=**0,6** [1/h]	for buildings built after 1995

Heat Gains

Heat gains are produced by other heat sources than space heating in a building. For instance, the internal heat gains are the heat generated by lighting, people, and equipment. It is largely dependent upon human behavior and standard of living (30). In this report the heat gains are divided into solar heat gains and internal heat gains.

Solar heat gains

The solar heat gains are calculated as followed (23):

$$q_r = T_s * W_c * W_f * S_w * I_{sol}$$

Where:

T_s is the coefficient of solar transmission of the window (0-1)

W_c is the shading coefficient of the window (0-1)

W_f is the frame coefficient of the window (0-1)

S_w is the total surface of windows of the building (m²)

I_{sol} is the global irradiation on horizontal surface (W/m²)

Since the $\boldsymbol{I_{sol}}$-values are provided in the weather file and the $\boldsymbol{S_w}$–values are extracted from IWU 2005, the remaining three values have to be found out from several sources:

The $\mathbf{T_s}$-value, in Germany known as the 'g-Wert' or 'g-Faktor', could, like the S_w-values, directly extract from IWU 2005 (38):

SFD: 0.63-0.76 and 0.87 for framework buildings

RH: 0.63-0.8

MFD: 0.63-0.76

AP: 0.76-0.86

HH: 0.7

The values for $\boldsymbol{W_f}$ were taken from IWU Energy Pass (39). Thereby, the common value for all building references is considered to be **0.7** (39).

According to the ordinance VDI 2078 the shading coefficient (b-value or $\boldsymbol{W_c}$) is the ratio of the g-value (= the T_s-value) of a glazed window to the g-value of an insulating glass without coating. In general the g-value is given with 80 % of the shading coefficient thus, **b = g/0.8**. (40), (41). Since the g-values are known from IWU Energy Pass (39), the W_c can be calculated by dividing them with 0.8. For single glazed windows the dividing factor is 0.87:

SFD: 0.78-0.95 and 0.98 for framework buildings

RH: 0.78-1

MFD: 0.78-0.95

AP: 0.95-0.98

HH: 0.87-0.95

The entire table with all the chosen T_s/g-values and W_c-values for each building reference are listed in Appendix CCC.

Internal heat gains:

The internal heat gain is calculated as the amount of the heat gains from appliances, lightning, people/occupants, and ventilations fans.

(a) Heat gains from appliances (A_c)

The values for the heat gains from appliances were directly extracted from IWU Energy Pass (39):

SFD/RH = 1.78 W/m^2

MFD = 2.28 W/m^2

Moreover, in IWU Energy Pass (39) only a value for high-rise building was provided. Hence, for simplification for AP and HH the same value was taken:

AP/HH = 2.66 W/m^2

(b) Heat gains from lightning (L_c)

From AEW the energy consumption for lightning per person and per year could be obtained with 1000 kWh/a (42). Furthermore, after Eurostat[6] the average amount of person per household in Germany was 2.1 in 2009 (43). Thus, we get an energy consumption of 24 W for lightning:

$$\frac{1000\ kWh * 2.1}{365\ d * 24h} = 24\ W$$

Running the simulation for our investigations the specific average lightning constant load in buildings was necessary. According to IWU 2009 the total heated floor area is given with 3,415 million m^2. Additionally, the amount of apartments is estimated with 39.43 million. Hence, for Germany we get an average floor area of 86.61 m^2 per household (3,415 million m^2 / 39.43 million).
This lead to the specific average lightning constant load of:

$$\frac{24\ W}{86.61\ m^6} = \mathbf{0.2773\ W/m^2}$$

Since the calculated value is an average for all type of dwellings, 0.2779 W/m^2 was used for all 122 building references.

[6] Eurostat main responsibilities are to provide statistical information to the institutions of the European Union (more about Eurostat in chapter 6)

(c) Heat gains from people/residents (O_c)

The specific heat gains from occupants were extracted from IWU Energy Pass.

SFD/RH = 1.11 W/m²

MFD = 1.43 W/m²

For the heat gains from appliances as well as for the heat gains from occupants IWU only provides values for residence halls but not separately for APs and HHs. For simplification the same value was taken for APs and HHs:

AP/HH = 2.00 W/m²

Zero values and others:

Efficiency of the heat recovery unit (H_{Rec_eff})

As mentioned previously the amount of dwellings with a heat recovery unit is very low in Germany. The share of buildings with a ventilation system is less than 1.5 % and only around half of them are coming with heat recovery. Moreover, just 10 % of the newly constructed buildings are equipped with a ventilation system (9).
Since the amount of buildings is negligible for Germany, H_{rec_eff} was set with zero.

Specific Fan Power (SFP) and heat losses of fan (Pfh)

Since the share of buildings using a fan is only 1.5 % the SFP-value and the Pfh-value were also set to zero.

Response capacity of a heating (cooling) system (P_c, P_h)

The assumption was made that the response capacity of the energy systems of the building was high. Hence, the P_c and P_h-values were set very high to ensure that the systems are able to reply to any change in the demand (21).

Maximum heating and cooling power of a heating and cooling system (S_c, S_h)

For the energy systems of the building the assumption was made that the provided energy is always meet the demand. Thus, the values for maximum heating and cooling power of a heating and cooling system were set very high to ensure the systems are able to provide the demanded energy (21).

5. Quantification of the building stock

For the quantification of the German building stock the numbers were mainly used from IWU since they provide for all the reference buildings accurate and reliable values. Unfortunately, not all values could take over directly because our housing typology differs in some points. For instance, we separate in High Towers (HH) and Apartment blocks while IWU 2011 considers them as one type of dwelling. The numbers from IWU and the adjusted ones for this report are presented in Appendix 5.

As stated in the previous chapters the segmentation is divided after the type of buildings, year of construction, and climate zones:

- Quantification after year of construction:

First of all, an overview of the entire German building stock by the year of construction is presented:

German Building Stock – Numbers of houses by building period							
	SFD	RH	MFD	AP+HH		Sum	Share
till 1918 Framework	370		50			420	2.33%
till 1918	1040	350	380	10		1780	9.87%
1919-1948	1280	800	460	10		2550	14.14%
1949-1957	920	480	390	30		1820	10.09%
1958-1968	1580	670	550	60		2860	15.85%
1969-1978	1470	650	320	80		2520	13.97%
1979-1983	750	380	160	30		1320	7.32%
1984-1994	1040	540	210	40		1830	10.14%
1995-2001	1080	500	200			1780	9.87%
2002-2009	790	300	70			1160	6.43%
Sum	10320	4670	2790	260		**18040**	
Share	57.21%	25.89%	15.47%	1.44%			100.00%

Table 11: Overview of the German building stock by period of construction - all values in Thousands - Changed after IWU 2009 (11).

As you can see from Table 11 we had a **total amount of buildings with 18.040 million in 2009.** Moreover, the majority buildings are single family dwellings or row houses. In addition, a moderate share of MFDs and a very small amount of apartment blocks and high-towers can be found in Germany.

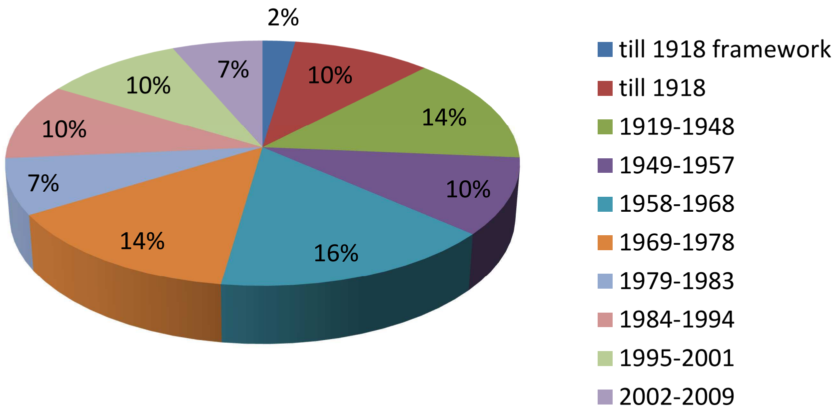

Figure 17: Distribution of the number of dwellings by years of construction in 2009

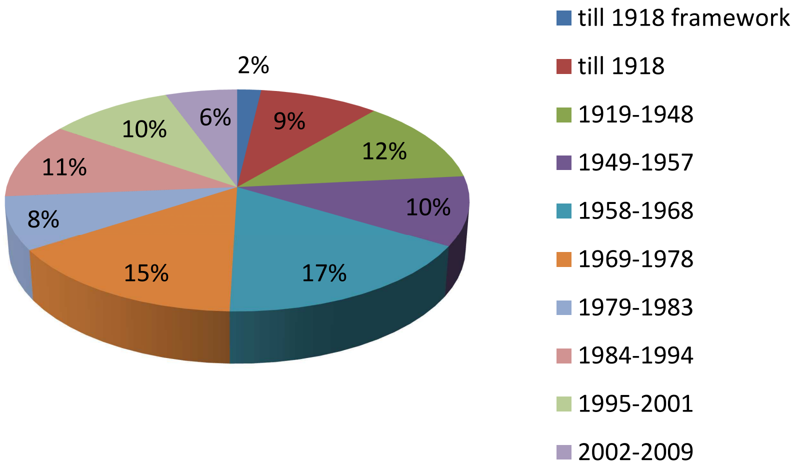

Figure 18: Distribution of the surface area by years of construction in 2009

In the reconstructions years (also known as the “Golden Fifties”) many buildings had been erected from the mid-fifties till the late sixties of the 20th century. Furthermore, as a result of the rapid growing birth-rate in the 1960s the demand for more living space was given. Thus, to avoid housing shortage many apartment blocks high towers were built till the late 1970s. After the reunification of Germany in 1990 the demand for new buildings increased again after it was dropped in the 1980s (see Figure 19).

Around four million buildings were erected before 1939, the year of the beginning of World War II. Those houses can be found especially in rural areas or in the historic center of a town.

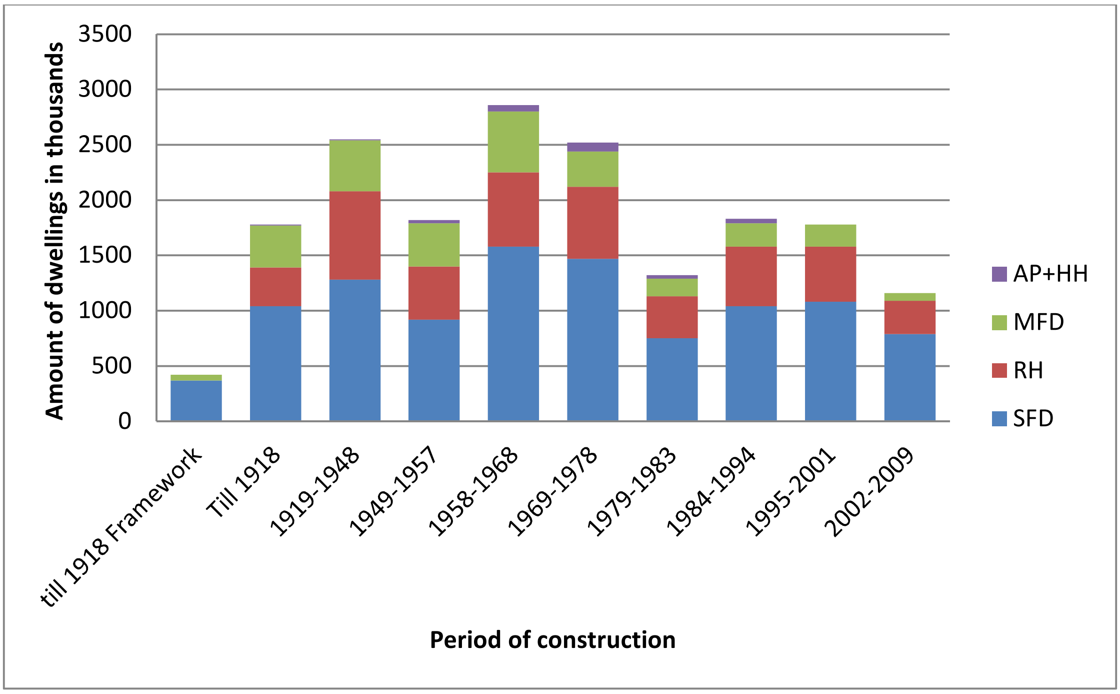

Figure 19: Numbers of houses in 2009 by period of construction and type of buildings.

❖ Quantification after the living area

Living area/surface area in million m²							
	SFD	RH	MFD	AP+HH		Sum	share
till 1918 Framework	51		13			64	1.87%
till 1918	155	43	112	10		320	9.37%
1919-1948	173	91	134	17		415	12.15%
1949-1957	127	57	131	31		346	10.13%
1958-1968	221	76	197	84		578	16.93%
1969-1978	213	78	109	127		527	15.43%
1979-1983	111	47	69	39		266	7.79%
1984-1994	148	66	76	84		374	10.95%
1995-2001	152	62	119			333	9.75%
2002-2009	114	37	41			192	5.62%
sum	1465	557	1001	392		3415	
share	42.90%	16.31%	29.31%	11.48%			100.00%

Table 12: The total living area in Germany in 2009 by year of construction. The values are given in million m².

The share of the distributed amount of houses is similar to the share of the surface area within a building period. For instance, for buildings which were built from 1958-1968 we have a share of buildings of 15.85 % (Table 11). The related surface area in this time period has a share of 16.93 % (Table 12).

But regarding the share after the type of housing we obtain greater deviations. After the number of buildings we have a share of around 57.21 % for SFDs (25.89 % for RHs, 15.47 % for MFDs, and 1.44 % for APs and HHs), whereas we get for the distribution of the living area a share of 42.90 % for SFDs (16.31 % for RHs, 29.31 % for MFDs, and 11.48 % for APs and HHs). The two figures below are giving a graphical view over the distribution of buildings.

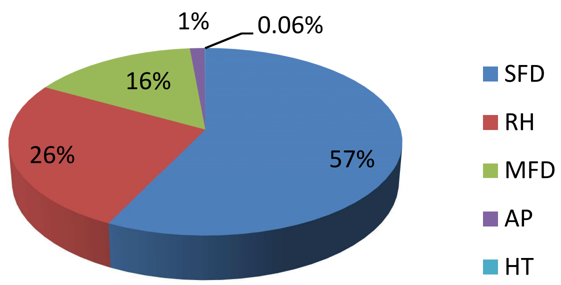

Figure 20: Distribution of the number of dwellings by type of buildings in 2009.

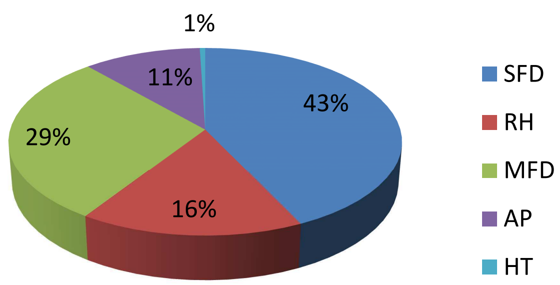

Figure 21: Distribution of the surface area by type of buildings in 2009.

Although the share of row houses is 10 % higher than the share of MFDs, the MFDs have a much higher amount of surface area because MFDs have an average of 5.03 apartments and are therefore bigger in area size. Apartment blocks also feature a high number of apartments that is why we have here a moderately high share of area of 11 %. Under the aspect of the surface area SFDs remain on top position, 57 % of the buildings are SFDs with a share of 43 % of total surface area. The absolute amount of HHs is so small that even the total surface area has a share of only 1 %.

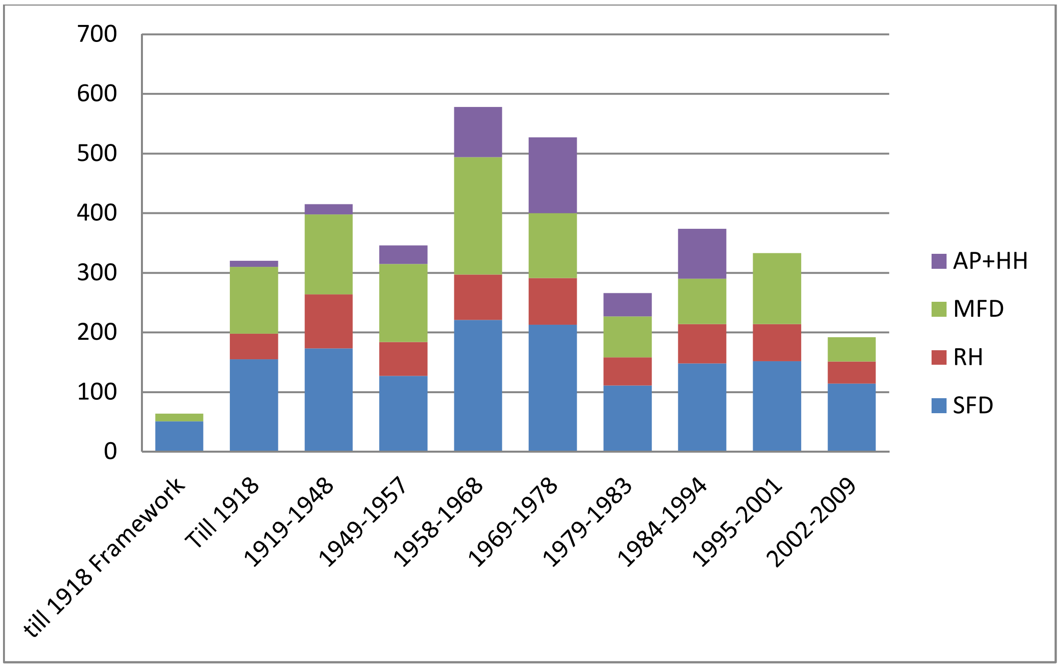

Figure 22: Distribution of living area in 2009 by year of construction and type of dwellings.

From Figure 19 and Figure 22 we can see the oscillation of the SFDs and MFDs while the RH houses have been building constantly over the years. Moreover, apartment blocks and especially high towers have not played a significant role in the building sector since 1995.

- Quantification after the number of apartments/dwellings

Numbers of apartments in Germany							
	SFD	RH	MFD	AP+HH		sum	share
till 1918 Framework	510		170			680	1.72%
till 1918	1370	470	1490	180		3510	8.90%
1919-1948	1720	960	1920	260		4860	12.33%
1949-1957	1240	570	2000	570		4380	11.11%
1958-1968	2150	770	2800	1450		7170	18.18%
1969-1978	1930	760	1500	2480		6670	16.92%
1979-1983	940	400	990	570		2900	7.35%
1984-1994	1230	590	1060	1290		4170	10.58%
1995-2001	1250	540	1600			3390	8.60%
2002-2009	880	310	510			1700	4.31%
Sum	13220	5370	14040	6800		39430	
share	33.53%	13.62%	35.61%	17.25%			100.00%

Table 13: Number of apartments in 2009 by year of construction and type of buildings - all values in Thousands

Although SFDs have in average only 1.28 apartments per buildings, they have the second highest total numbers of apartments with 13.220 million units. In addition, most of the apartments per building can be found within MFDs with an absolute amount of 140.4 million. In the reconstruction years, after World War II, mainly bigger houses with a great deal of apartments were built: Almost 4 million apartments within apartment blocks/high towers and 6.3 million apartments in MFD buildings.

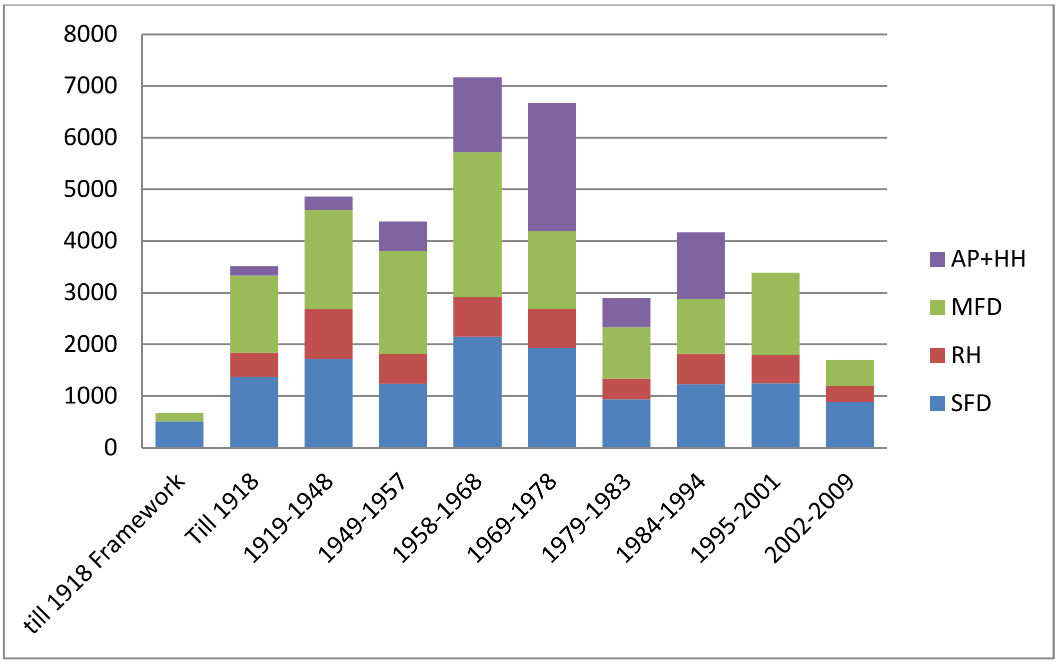

Table 14: Numbers of apartments

- Quantification after climate zones

Since we merged, for simplification, the two winter climate zones into one single zone A (see Figure 13), we have here the biggest quantity of buildings with around 8,372,000 million. Climate zone B consists, like Zone A, of seven states, but the states in zone B have a much lower population, and therefore less buildings were built there. Approximately 5.98 million houses can be found in climate zone B. Bavaria and Saxony form climate zone C and have a total amount of buildings of 3.68 million.

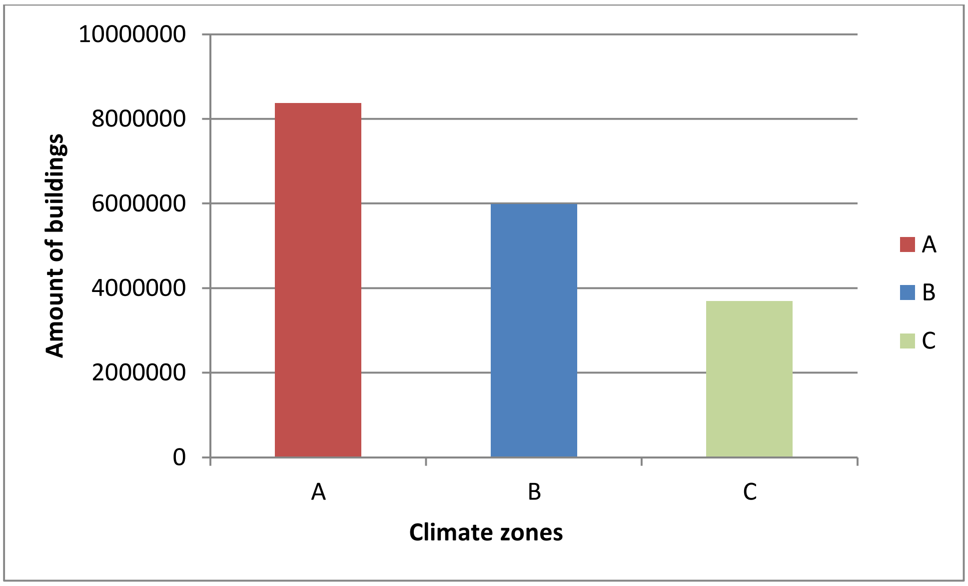

Table 15: Numbers of buildings by the three climate zones

In Figure 23 the number of dwellings in each climate zone is presented. In Figure 24 the distribution of the surface area by the three climate zones. Thereby, we have an almost identical share. 46 % of the buildings and coincidentally 45 % of the total

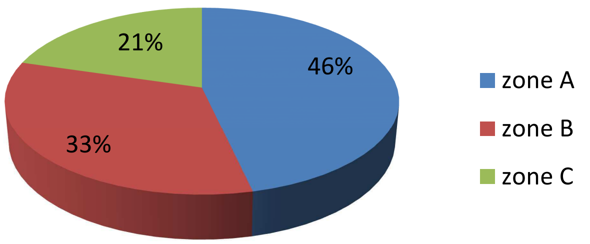

Figure 23: Distribution of the number of dwellings by climate zone in 2009.

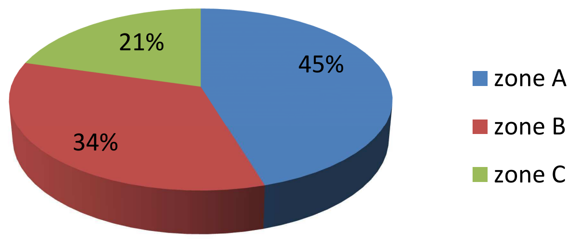

Figure 24: Distribution of the surface area by climate zone in 2009.

surface area are in zone A. Similar for the other zones: 33 % and 21 % of dwellings in zone B and C compared to a share of 34 % and 21 % of surface area.

Overview of the characterization

In this section the average physical parameters and technical characters the German residential buildings are presented:

An average residential building in Germany has:	**2.186 apartments** per building
	189.30 m^2 is the heated floor area
	271.67 m^2 is the amount of external surface area
	1196.74 m^3 is the heated volume of a building
	8.8 1/h is the natural ventilation rate, if the window is opened
	For the average sanitary ventilation rate we got: **0.85 1/h** for buildings older than 1979 **0.75 1/h** for buildings built from 1979-1994 **0.6 1/h** for buildings built after 1995
	1.217 W/m^2K as the average U-value
	180,940 KJ/K is the average heat capacity of a dwelling
SFDs have in average:	**141.95 m^2** heated floor area
	1.28 apartments per dwelling
	An U-value of **1.146 W/m^2K**
RHs have in average:	**119.27 m^2** heated floor area
	1.15 apartments per building
	An U-value of **1.158 W/m^2K**
MFDs have in average:	**358.78 m^2** heated floor area

5.03 apartments per building

An U-value of **1.523 W/m^{2}K**

APs and HHs[7] have in average: **1507.88 m^2** heated floor area

26.15 apartments per building

An U-value of **1.769 W/m^{2}K**

[7] since the share of HHs is very small they were considered here together with APs

6. Results

Since the results from the EABS model are provided in useful energy demands a conversation into final energy demands has to be made to compare the values from the simulation with available data in national and international databases.
In the final subsection the results are presented after the criteria of the building segmentation which are depicted in chapter 3.

The used national and international references are Eurostat, 'Statistisches Bundesamt Wiesbaden' and the 'Bundenministerium fur Wirtschaft und Technologie' (German ministry of economics and technology) which are providing there data in final energy demands.

6.1 Conversion of the useful energy demands into final energy demands

To convert our results into comparable values the losses and efficiencies of the several heat generators and hot water producers have to be considered:

Firstly, the distribution of the several heat and hot water generators/producers in Germany was acquired from IWU 2010:

Heating:

Heating generators	Share
Boiler	86.5 %
Oven/Furnace	5.2 %
(direct) electrial heaters	2.6 %
Heating pump	1.8 %
District Heating	3.9 %
	100 %

Table 16: Distribution of the several heating generators (indepdent from the usesd fuel) (9)

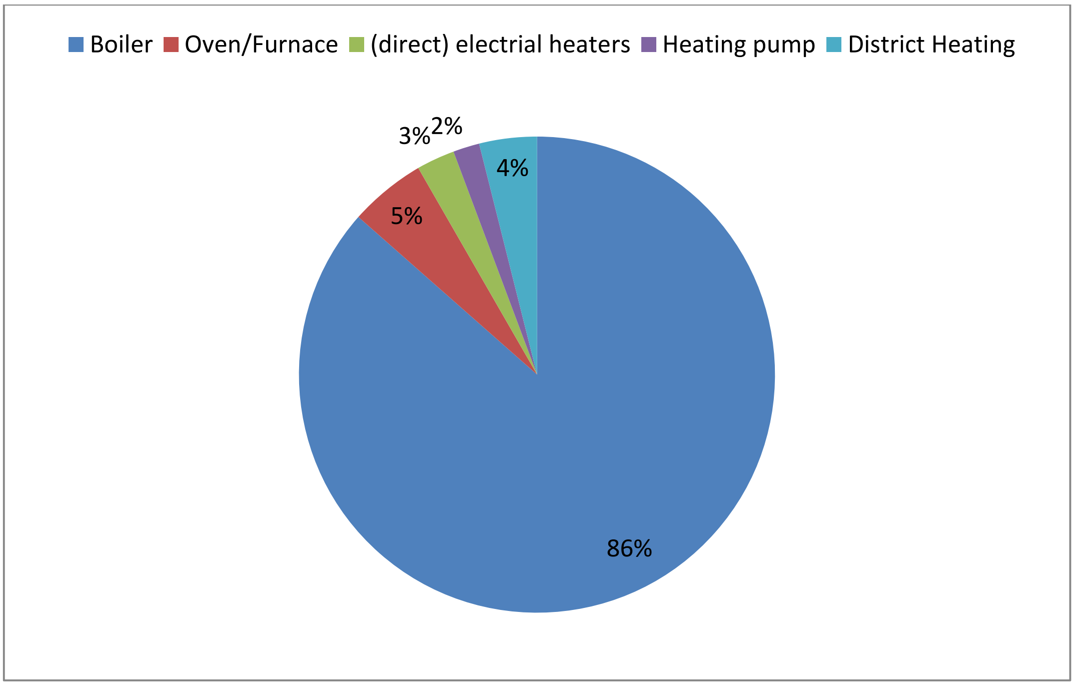

Figure 25: Graphical overview of the several heating producers (9).

Hot water:

Hot water production	Share		Share
in combination (see third column) with heaters	76.9 %	Boiler	86.5 %
		Oven/Furnace	5.2 %
		(direct) elctrial heaters	2.6 %
		Heating pump	1.8 %
		District Heating	3.9 %
electrical water heating	12.1 %		
elec. hot water storage tank	4.8 %		
Gas water heating	2.5 %		
combustible hot water storage tank	3.3 %		
outgoing air/exhaust air heating pump	0.4 %		
	100 %		100%

Table 17: Distribution of the several hot water generators in Germany (9)

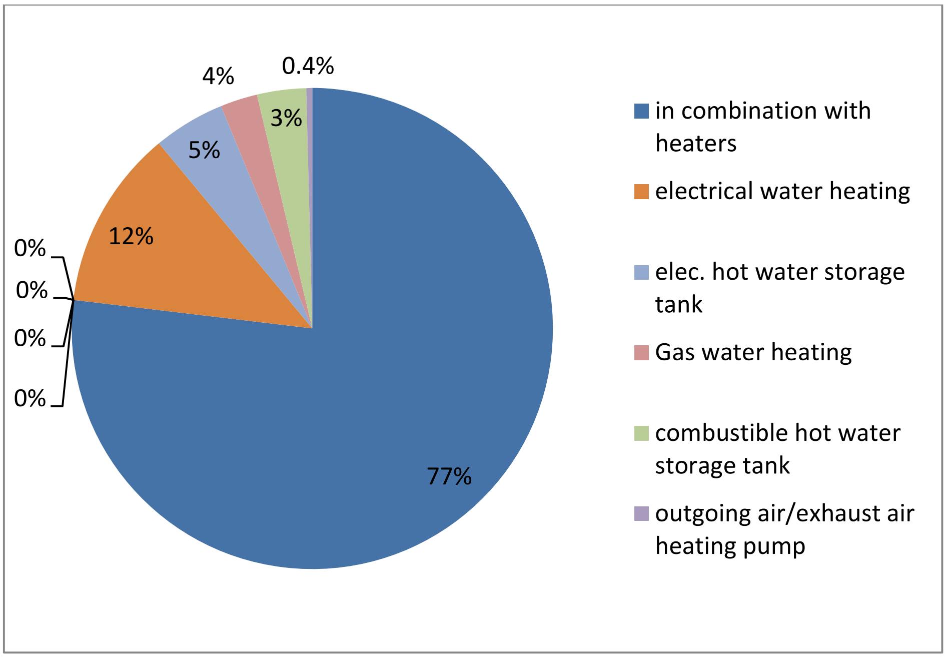

Figure 26: Graphical overview of the distribution of the several hot water generators (9)

In the second step, the ‘Erzeugeraufwandszahlen‘ =EAZ (“the effort of generating numbers”) from IWU 2005/2 (44) and (39) were taken into account. The EAZ is the ratio of useful energy to final energy demand. Thus, those numbers describe the losses of the several generators:

<u>Heating:</u>

Heating generators	Erzeugeraufwandszahl
Boiler	1.33
Oven/Furnace	1.5
(direct) electrial heaters	1
Heating pump	0.35
District Heating	1.02

Table 18: “The effort of generating numbers” for the several heating generators in Germany (39)

<u>Hot water:</u>

Hot water production		Erzeugeraufwandszahl
in combination with heaters	Boiler	1.18
	Oven/Furnace	1.5
	(direct) electrial heaters	1
	Heating pump	0.35
	District Heating	1.14
electrical water heating		1

elec. hot water storage tank		1
Gas water heating		1.2
combustible hot water storage tank		1.22
outgoing air/exhaust air heating pump		0.35

Table 19: "The effort of generating numbers" for the several hot water generators in Germany (39)

With the given share of the several generators and the EAZ the final energy values could be calculated. Thereby, the results for each generator from the simulation (useful energy – see Table 20) were multiplied by the related share and EAZ. Adding up the separate final energy demands for each generator provided the total final energy demands (final energy – see Table 21)

The results for the energy demand which were calculated by the simulation:

Energy demand/useful energy	
Energy sorces	Simulation [TWh/a]
Space Heating	496.10
Lightening	7.94
Appliances	58.07
Hot water	52.29
Hydronic pumps	11.46
Total	625.87

Table 20: Results of the simulation – useful energy

And the results for the simulation after transforming the useful energy of the space heating and hot water into final energy:

Energy demand/final energy	
Energy sorces	Simulation [TWh/a]
Space Heating	**560.66**
Lightening	7.94
Appliances	58.06
Hot water	**59.85**
Hydronic pumps	11.45
Total	697.98

Table 21: Transformed results of the simulation in final energy demands

The results for the other energy sources remain the same since they have already been comparable.

For the determiniation of the final energy demand the type of fuel for the heating generators was not needed to be known. Since it is/ might be necessary for further invesigations/calculations (for instance, the calculation of the CO_2 emissions) a table with the different type of fuels for the space heating generators is presented in Table 22: Share of fuels for space heatingTable 22. Further information concerning the type of fuel can be found in IWU 2010 (9).

Type of fuel	**Building erected**		
	before 1978	1978 - 2004	2005
District heating	3.9 %	4 %	3.6 %
Gas	47.9 %	59.8 %	60.1 %
Oil	37.2 %	29.4 %	5.9 %
Biomass	6.5 %	2.6 %	9.2 %
Coal	1 %	0 %	0 %
Electrical	3.5 %	4.3 %	21.1 %

Table 22: Share of fuels for space heating. Data are provided from IWU 2011 (9)

6.2 Comparision of the results with databases

As mentioned in the beginning of the chapter, three different databases are available to compare the results from the EABS model: The international database Eurostat and the national databases “statistisches Bundesamt Wiesbaden” and sources from the German ministry of economics and technology (BMFWUE).

(a) statistisches Bundesamt Wiesbaden (all values in TWh/a))

	Simulation	**stat. Bundesamt WI**
Space Heating	560.66	492
Lightening	7.94	11
Appliances	58.07	60
Hot water	59.85	82
Hydronic pumps	11.46	-
Total	697.98	680

Table 23: Results compared with stat. Bundesamt

The statistisches Bundesamt (45) is the only database where the energy consumptions for the several generators are listed separately. Our calculations led to a total energy demand of **697.983 TWh, what is just 3 % more than the value from the statistisches Bundesamt**. Furthermore, we have similar results for appliances and lightening. The result for hot water is around 27 % lower and **for heating approximately 14 % higher**. For space heating the database provides an absolute value of 468 TWh. Since the temperature-adjusted value is given with 656 TWh (680 TWh – 656 TWh = 24 TWh lower than the non-temperature-adjusted total value) the difference of 24 TWh can be added up to the space heating: 468 TWh + 24 TWh = 492 TWh.
Unfortunately, in the database no result was given for hydronic pumps. The reference year is as in our simulation 2009.

(b) Eurostat (all values in TWh/a))

	Simulation	Eurostat
Space Heating	560.66	553.57
Lightening	7.94	-
Appliances	58.07	-
Hot water	59.85	-
Hydronic pumps	11.46	-
Total	697.98	765.09

Table 24: Results compared with Eurostat

The international database Eurostat provides only the value for the total final energy demand. Since we have the biggest potential of CO_2 savings in space heating and most of the parameters in our simulation are also affecting those values a deeper look into the other energy sources is not necessary.
In the previous database, (a) statistisches Bundesamt, **the share of space heating is 72.35 % of the total value**. Therefore, it was assumed that for Eurostat the share in space heating is also 72.35 % which led to **553.57 TWh/a, what is only 1.3 % lower than our determined value for space heating**. The database reference year is 2009.

(c) Federal ministry of economics and technology (BMFWUE) (all values in TWh/a))

	Simulation	BMFWUE
Space Heating	560.65	498.02
Lightening	7.94	-
Appliances	58.06	-
Hot water	59.85	-
Hydronic pumps	11.45	-
Total	697.98	688.32

Table 25: Results compared with the BMFWUE

The federal ministry (46) also provides only the total final energy value for the residential stock in Germany with 688.328 TWh what is only **1.3 more than our total value.** Therefore, the same assumption as for the Eurostat database was made. Thus, the share in space heating is 72.353 % of the total value which led to 498.026 TWh for 2009. That is **around 12 % less for space heating than we have calculated**.

Results in a nutshell:

The results for the final energy of lightning and appliances are quite close to the values of the national database 'statistisches Bundesamt'. This might be the case because for each of these energy sources only one input parameter had to be determined to run the EABS simulation: A_c for appliances and L_c for lightning.
Although for the heating power of the hot water demand also only one input parameter was necessary, we got a 37 % lower result than in the database of the 'statistisches Bundesamt'. Since the heating power for hot water is depended on the number of persons per household (which cannot be considered in the EABS model) the value is related to very high uncertainties.
Unfortunately, none of the three references are providing a value for the hydronic pumps.
The most important energy demand which was investigated in this report was the space heating. First of all, it has the highest potential of CO_2 savings because it generates the most energy. Secondly, the space heating was the most challenging calculating value since many physical parameters had to be determined from several sources.
As already mentioned in the previous chapter, the international database Eurostat provides only a 1.3 % lower value as our simulation. That indicates that the EABS model is showing a very high consistency.
The 'statistisches Bundesamt' and the German federal ministry of economics and technology provide values of 492 TWh and 498.03 TWh. That means a deviation of -12.2 % and -11.2 %. Thus, we get a range of deviation of -12.2 % up to -1.3 %

compared to the initial value of 560.66 TWh. This proves again the verification of the EABS modeling.
Furthermore, both German databases have similar total final energy values with 680 TWh and 688.32 TWh which are with -2.6 % and -1.4 % slightly lower than the simulation values.
On the other side we obtain from Eurostat 765.09 TWh for the total energy demand which is around 9.5 % higher than the calculated starting position.
To emphasize the importance of space heating, in the figure below the share in final energy after the several sources from the EABS simulation are shown.

Final energy demand in TWh in 2009				
	Simulation/ EABS Model	stat. Bundesamt	Ministry of Economy	Eurostat
Space Heating	560.66	492	498.03	553.57
Lightening	7.94	11	-	-
Appliances	58.07	60	-	-
Hot water	59.85	82	-	-
Hydronic pumps	11.46	-	-	-
Total	**697.98**	**680**	**688.32**	**765.09**

Table 26: Final energy demand compared to other databases

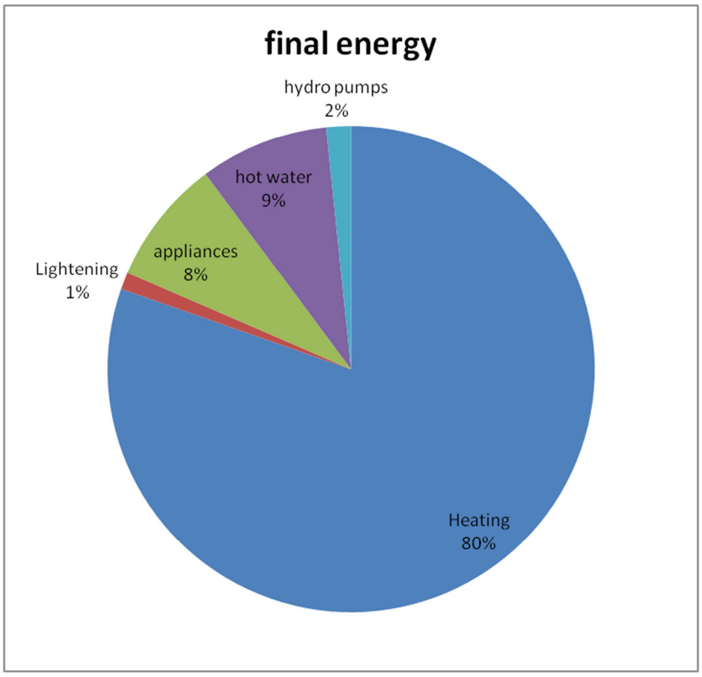

Figure 27: Share of the final energy demands

6.3 Determiniation of the final energy demand in KWh/m²

In the previous subsection the results of the simulation were presented and compared with national and international databases.

The following tables report the energy demand in 2009 as obtained in this work in terms of KWh/m^2:

All buildings	Useful energy[KWh/m²]	Final energy [KWh/m²]
Heating	151.72	171.47
Hot water	15.99	18.30
Electricity	23.69	23.69
Total	191.41	213.46

Table 27: National energy demand of the residential buildings in 2009

For heating the useful energy is 11.3 % lower than the final energy which means that there are losses of around 20 KWh/m^2. For the how water production the useful energy is 11.4 % lower than the final energy. Thus, for all the following results in KWh/m² the useful to final energy **factor** is given with **1.13 for the heating** and for the **hot water with 1.14**. By including the consumption for hot water and electricity the total useful energy is 10.3 % lower than the total final energy.

- Outputs after type of building:

	Useful energy[KWh/m²]	Final energy [KWh/m²]
	SFD	
Heating	128.67	145.41
Hot water	10.194	11.66
Electricity	21.53	21.52
Total	160.38	178.60
	RH	
Heating	75.36	85.17
Hot water	11.68	13.37
Electricity	21.52	21.52
Total	108.57	120.07
	MFD	
Heating	214.82	242.78
Hot water	21.58	24.70

Electricity	25.90	25.90
Total	262.31	293.39
	AP	
Heating	181.87	205.54
Hot water	29.58	33.85
Electricity	29.23	29.23
Total	240.69	268.63
	HH	
Heating	259.47	293.23
Hot water	28.97	33.16
Electricity	29.23	29.23
Total	317.68	355.63

Table 28: Energy demands in 2009 after type of dwellings

In 2009 row houses had the lowest total useful energy consumption of 109KWh/m². Conversely, the highest value with 318 KWh/m² was reached by high towers. In HHs and APs the energy demand for hot water and electricity is similar (around 29 KWh/m² for APs and HHs) while we have for SFDs and RHs a greater difference of approximately 10 KWh/m². For MFDs the consumption of hot water is with 22 KWh/m² slightly lower than for electricity.
Since most of the MFDs, APs, and HHs were built in a period when the housing demands in Germany where very high and no thermal regulations were in effect, their energy efficiency is considered as very low. Therefore, the acquired values for those types of buildings have the highest energy consumptions.

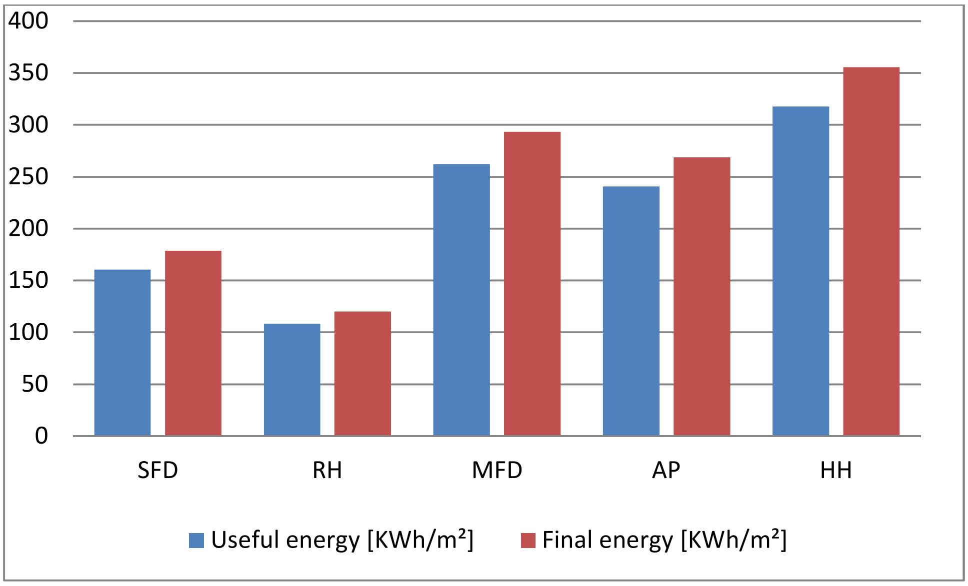

Figure 28: Graphical overview of the energy demands by type of dwelling

The results for the total final energy are slightly higher because of the useful to final energy factor of 1.13 / 1.14 for heating and hot water production.

❖ Outputs after climate zones

	Useful energy [KWh/m²]	Final energy [KWh/m²]
Climate zone A		
Heating	142.24	160.75
Hot water	15.62	17.88
Electricity	23.54	23.54
Total	181.41	202.18
Climate zone B		
Heating	152.04	171.83
Hot water	16.43	18.81
Electricity	23.87	23.87
Total	192.36	214.52
Climate zone C		
Heating	172.10	194.49
Hot water	16.05	18.38
Electricity	23.72	23.72
Total	211.88	236.60

Table 29: Energy demands in 2009 by climate zones

The distribution of energy consumption in the several climate zones is for electricity and hot water almost consistent (round about 23.5 KWh/m² for electricity and 16 KWh/m² for hot water). For the heating demands there are significant differences. While in climate zone A the total final energy demand was 161 KWh/m² the total energy consumption for all buildings in zone C was with 194 KWh/m² much higher in 2009.
The huge deviations are related to the average temperature in the different climate zones (see also section 3.2). In zone C the average temperature is 7.73 °C, 1.9 °C lower than in zone A, hence, the highest consumption of heating is given in zone C. In Table 30 the correspondence of lower temperatures with higher total energy consumptions is depicted.

Climate zone	Temperature [°C]	Total final energy [kwh/m² y]
A	9.61	202.18
B	8.99	214.52
C	7.73	236.60

Table 30: Average temperature in relation with the total final energy in 2009

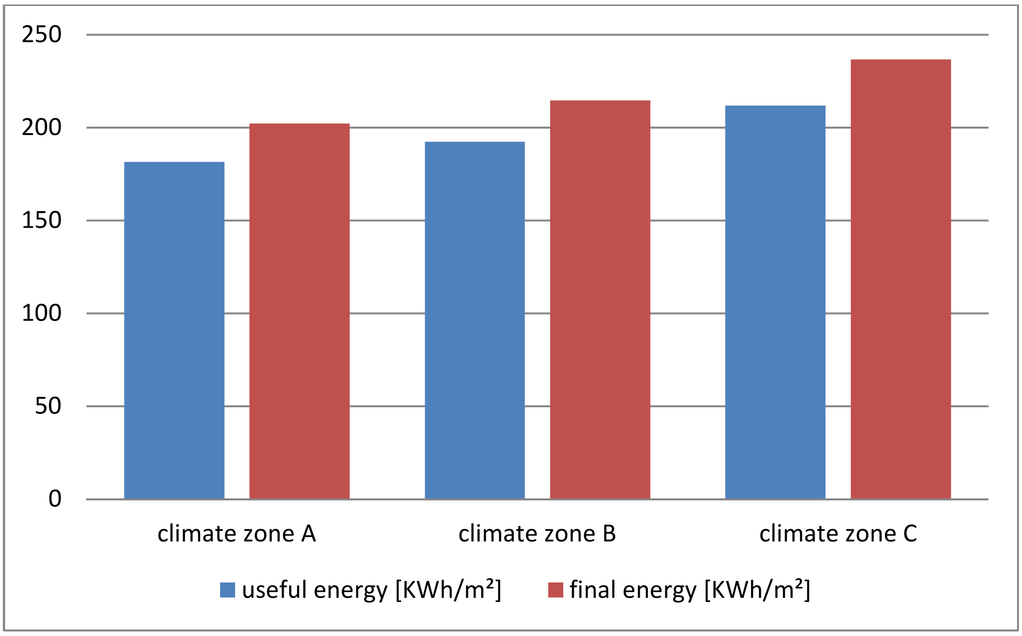

Figure 29: Graphical overview of the total energy consumption by climate zones

❖ Outputs after year of construction

	Useful energy [KWh/m²]	Final energy [KWh/m²]
	till 1918 framework	
Heating	248.84	281.22
Hot water	12.50	14.31
Electricity	22.42	22.42
Total	283.76	317.95
	till 1918	
Heating	165.23	186.73
Hot water	14.57	16.68
Electricity	23.15	23.15
Total	202.95	226.56
	1919-1948	
Heating	169.52	191.58
Hot water	14.99	17.16
Electricity	23.25	23.26
Total	207.77	232.00
	1949-1957	
Heating	148.89	168.26
Hot water	16.49	18.87
Electricity	23.87	23.87
Total	189.25	211.01

1958-1968		
Heating	308.32	348.44
Hot water	17.08	19.55
Electricity	24.13	24.13
Total	349.55	392.14
1969-1978		
Heating	124.19	140.35
Hot water	18.94	21.68
Electricity	24.90	24.90
Total	168.05	186.95
1979-1983		
Heating	89.60	101.26
Hot water	15.51	17.75
Electricity	23.49	23.49
Total	128.60	142.51
1984-1994		
Heating	95.10	107.48
Hot water	14.60	16.72
Electricity	23.12	23.12
Total	132.83	147.32
1995-2001		
Heating	45.95	51.93
Hot water	14.54	16.64
Electricity	23.09	23.09
Total	83.59	91.67
2002-2009		
Heating	63.08	71.29
Hot water	12.91	14.78
Electricity	22.46	22.46
Total	98.46	108.53

Table 31: Energy demands of residential buildings in 2009 by year of construction

Framework buildings which were erected before 1918 have a very high consumption of heating energy: Useful energy demand of 248.84 KWh/m² and final energy demand of 281.22 KWh/m². Non-framework residential houses that were built in the same time period show a 33 % lower heating energy consumption. The values for the next two consecutive periods of construction have similar heating demands (169.52 KWh/m² and 148.89 KWh/m²). For the period from 1958 till 1968 the highest values for heating were calculated with 308.33 KWh/m².

Due to the supposed housing shortage (see also section 3.2) many low-cost and low-quality MFDs, apartment blocks and high towers had been building in the booming reconstruction years till 1968. Moreover, a material shortage was the reason why cheap, new and low quality components had to be used for those type of buildings

while SFDs were built after traditional construction methods. That has been resulted in MFDs, APs, and HHs (mainly “Plattenbausiedlungen”) with a lack of good thermal insulation (25).
In the following years the energy demands decreased eminently. One reason is the introduction of ordinances and regulations. The lowest final energy demands for heating were reached in the period from 1995 and 2001 with 83.03 KWh/m².

The energy demands for hot water production have varied a lot over the years. The lowest amount of usage with 12.50 KWh/m² was measured for framework buildings built before 1918. Conversely, the highest value was simulated for buildings that had been erected from 1698 till 1978 (18.95 KWh/m²).

The electric consumption has oscillated between 22.41 KWh/m² for framework buildings erected before 1918 and 24.91 KWh/m²for the period of 1969 till 1978.

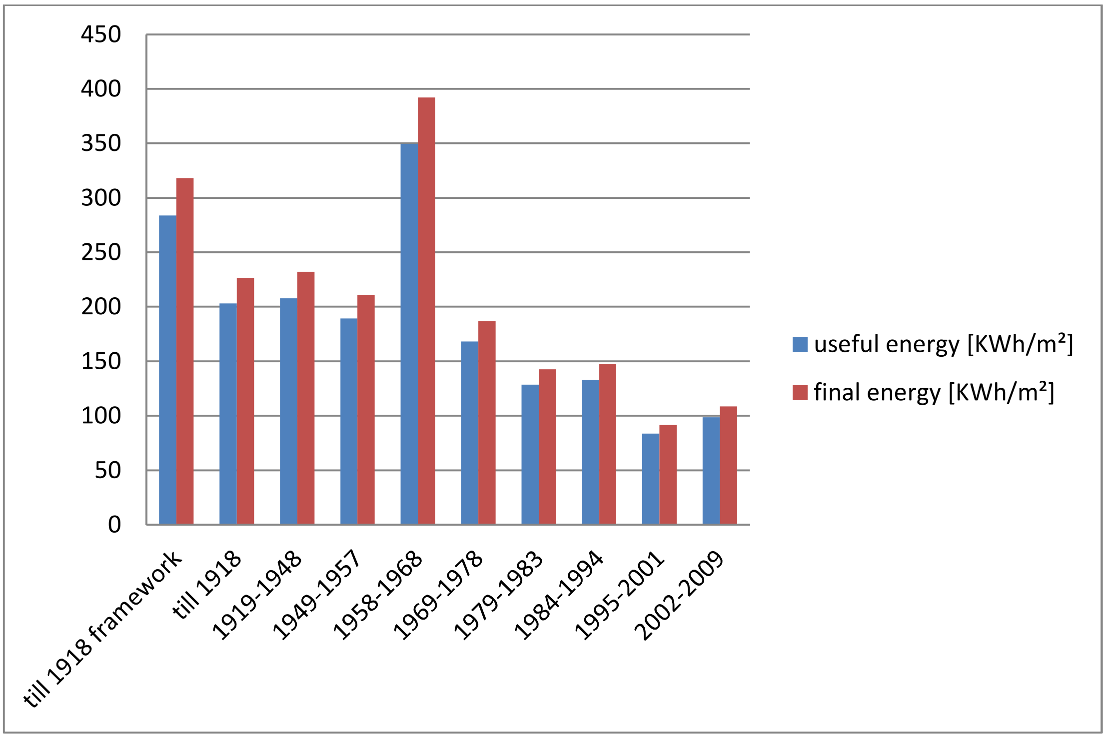

Table 32: Graphical overview of the energy demands in 2009 by year of construction

7. Sensitivity analysis

To analyze the influence of the several physical parameters on the results for the EABS model, a sensitivity analysis was conducted. Thereby, the values of each physical parameter were changed proportionally from their original state (± 10 %, ± 30 %, ± 50 %).
Since the segmentation and the results of the simulation are based on the reference year 2009, the same applies for the values which were used for the sensitivity analysis.

In the first part of this chapter all the characteristic data are presented in a figure to have a better direct comparison of each physical parameter.
In the second part of this chapter the modification of the most important physical values are described in detail.

7.1 Concerning all parameters

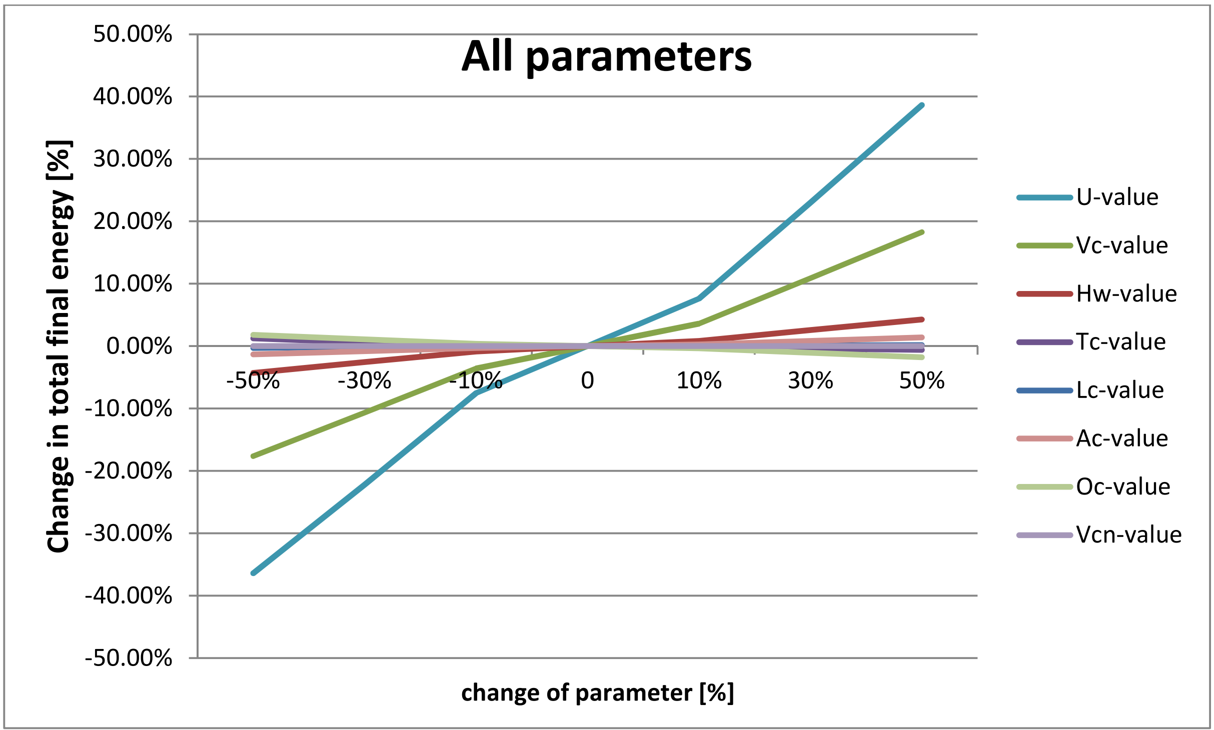

Figure 30: Effect of each physical parameter in relative values obtained from the sensitivity analysis

It can be seen from Figure 30 that the U-value, the sanitary ventilation rate (V_c), and the value for heating power demand for hot water production (H_w) have the biggest impact on the energy consumption of the German building stock. Conversely, the heat gains from appliances (A_c), occupants (O_c), and lightning (L_c), the effective heat capacity of a building (TC) and especially the natural ventilation rate (V_{cn}) show very little oscillations.

In the next graphic the absolute values for the energy consumption in relation to the modifications of the physical values are illustrated:

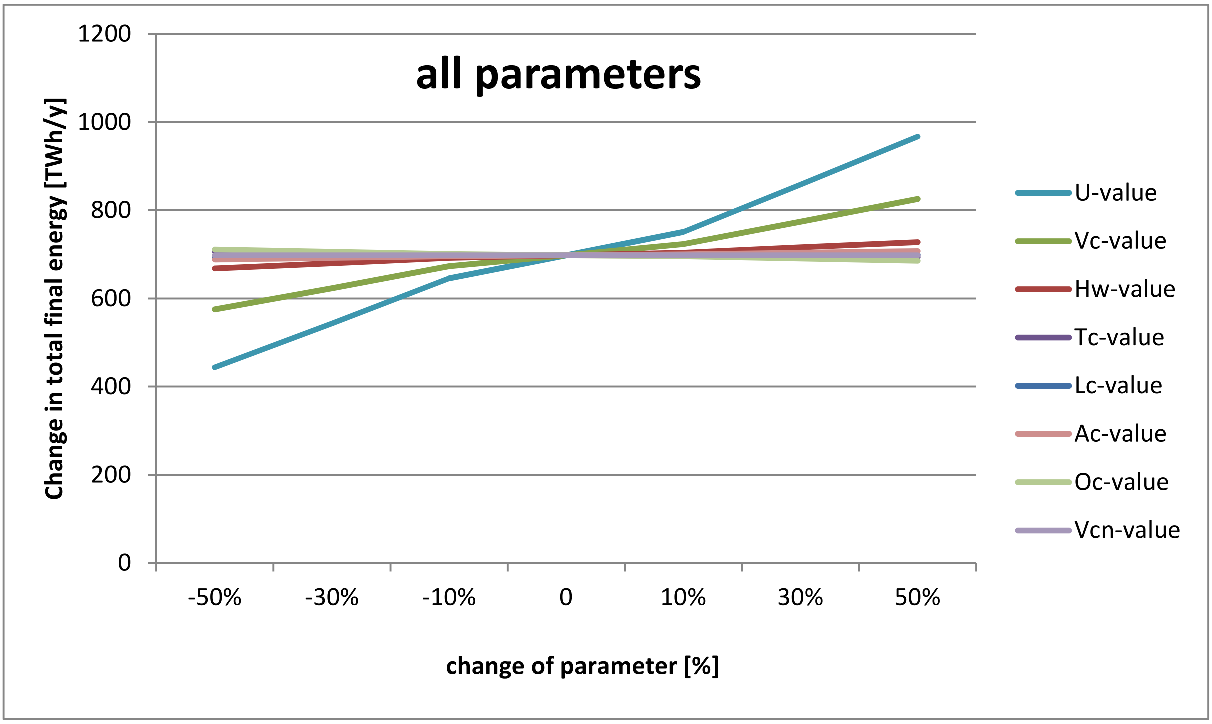

Figure 31: Effect of each physical parameter in absolute values (final energy) obtained from the sensitivity analysis

As shown in Figure 31 the curve progression of the U-values shows the biggest slopes in the range of – 50 % till -10 % and + 10 % till + 50 %. In the range of – 10 % and + 10 % the slope is flattened. This pattern of curve progression also applies for the Vc- and Hw-values.
For a 50 % lower U-value a total final energy of 443.87 TWh/y was simulated while for a 50 % higher U-value 967.54 TWh/y was calculated – a difference of approximately 500 TWh/y on the one side (see also chaper 7.2) On the other side, the variation of final energy demands for the natural ventilation rate (Vcn) is marginal: For modifications between – 50 % and 50 % from the original value, the final energy demand remained for all simulations at around 697.98 TWh/y. Thus, here is absolute no energy saving potential available.
In general, the variations of the other physical parameters had a much lower effect on the energy consumption then the alterations of the U-values.

Moreover, since the modification of the hot water values led to moderate-high relative values (Figure 30), the changes in absolute values can be considered as quite modest (Figure 31).
The absolute values for some other less relevant simulated cases are presented in Appendix 6.

7.2 Concerning the most vital parameters

Before presenting the results of the sensitivity analysis for the most important parameters, an additional sensitive analysis for various indoor and outdoor temperatures was made:

- Modification of the indoor and outdoor temperature:

Regarding that the climate change has been in process and the temperatures tend to increase within the next decades, those effects might have a crucial impact on the final energy demand of the German building stock. Furthermore, since the weather is stochastic the average temperatures vary annually. Moreover, the climate has been changing over the last 20 years, whereas the weather files from Meteonorm only represent the average temperature till 1990. Therefore, an extra investigation about the influence of the indoor and outdoor temperatures was made:

First of all, a reasonable range of temperature had to be determined for the sensitivity analysis. Hence, the average air temperatures over the last ten years were examined (see Table 33). Thereby, the values vary from 7.8 °C in 2010 up to 9.9 °C in 2007, a scope of 2.1 °C. Therefore, an additional simulation with a deviation of –1 °C and + 1 °C was conducted.

As the indoor temperature is closely related to the outdoor weather conditions also an analysis of the minimum desired indoor temperature has to be considered. To simplify matters the same range of temperature was taken.

Year	Average Temperature
2011	9.6 °C
2010	7.8 °C
2009	9.2 °C
2008	9.5 °C
2007	9.9 °C
2006	9.5 °C
2005	9.0 °C
2004	9.0 °C

2003	9.4 °C
2002	9.6 °C
2001	9.0 °C

Table 33: Overview over the average air (outdoor) temperatures in Germany over the last 10 years (Source Deutscher Wetterdienst, DWD (47))

Secondly, to run the simulation under the two adjusted temperature conditions, for each of the three climate regions (see chapter 3.2) a suitable weather station had to be found. Thus, for the simulation with + 1 ° C and – 1 ° C the following stations were determined from Meteonorm:

For +1°C:

Climate zone 1: Frankfurt with 10.66°C (compared to Essen with 9.61°C)

Climate zone 2: Freiburg with 10.2°C (compared to Stuttgart with 8.99°C)

Climate zone 3: Nuremberg with 8.79°C (compared to Munich with 7.73°C)

For -1°C:

Climate zone 1: Kassel with 8.6°C (compared to Essen with 9.61°C)

Climate zone 2: Coburg with 8.07 °C (compared to Stuttgart with 8.99°C)

Climate zone 3: Dresden with 6.03°C (compared to Munich with 7.73°C)

Meteonorm does not provide a weather station for climate zone 3 which is approximately one centigrade lower in average air temperature than the Munich weather station. The chosen one, Dresden, has a mean value of 6.03 °C which is 1.7 °C lower. This might be an appropriate explanation for the kink in the curve progression of the outdoor temperature in Figure 33 and Figure 34. Due to the much lower average temperature (- 1.7 °C instead of – 1 °C), there is supposed to be a higher heating demand in the winter months. Moreover, from the figures below, it can be derived that the outdoor climate conditions play a significant role in the heating consumption of the German building stock. On the one hand, an alteration of – 1 °C could cause a 15 % higher final energy demand. On the other hand, by having + 1 °C warmer air temperatures, a saving of 5 % could be reached. But again, the taken weather files are associated with uncertainties, since Meteonorm only supplies mean climate values up to 1990 (continuous increase of temperature since 1990 is not considered) and because of the variation of the average temperature each year. In

Figure 32 the climate changes since 1900 (annual variation and the continuous temperature increases) are graphical illustrated.

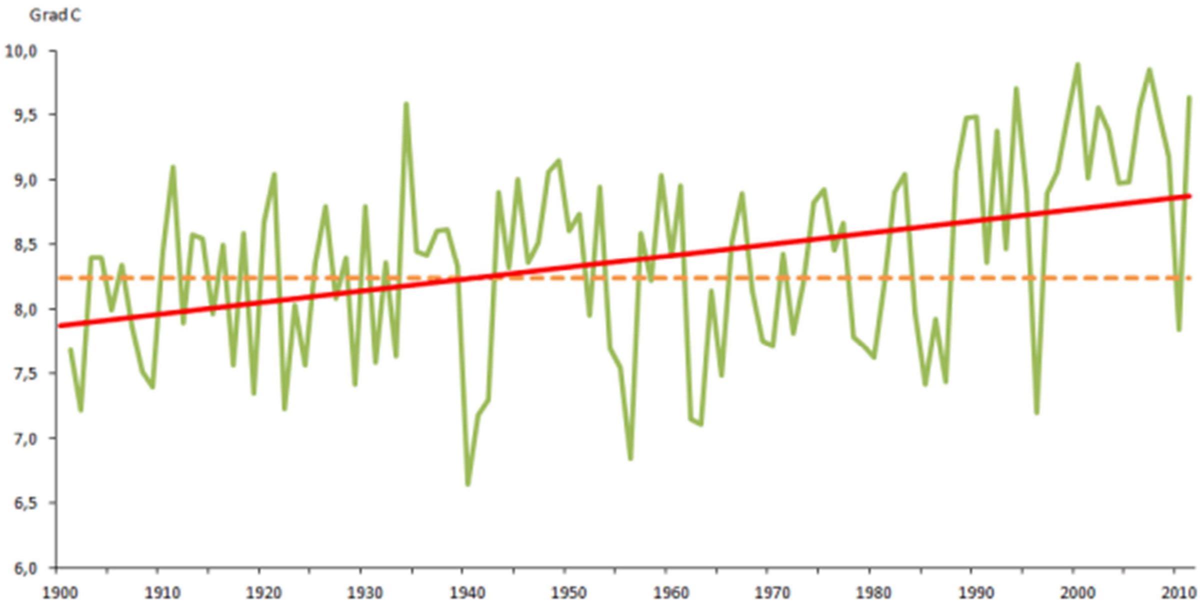

Figure 32: Changes of the average temperatures in Germany since 1900 (red line) and variation of the annual average temperature (green line) (48)

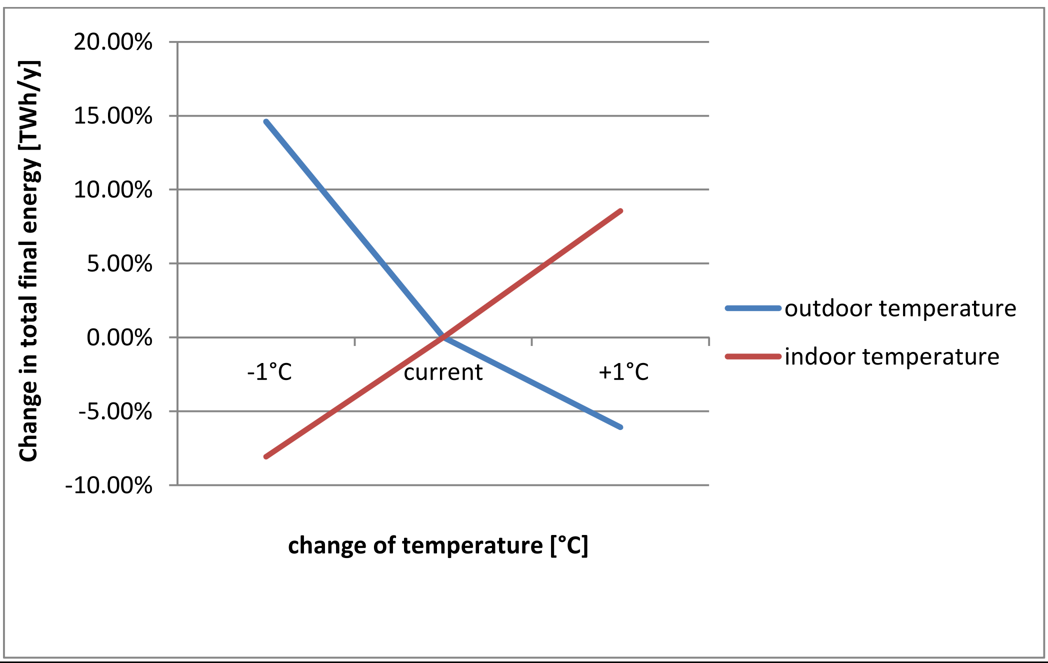

Figure 33: The indoor and outdoor temperatures in relative values obtained from the sensitivity analysis

Figure 33 and Figure 34 show that for setting the T_{rmin} at 19 °C (+ 1°C) an increase of 8.55 % to 757 TWh would occur. Conversely, a value of 17 °C (- 1 °C) would change the total final energy demand to -8.07 % and 642 TWh. It follows that even the modification of the indoor temperatures are providing a moderate-high potential of saving CO_2.

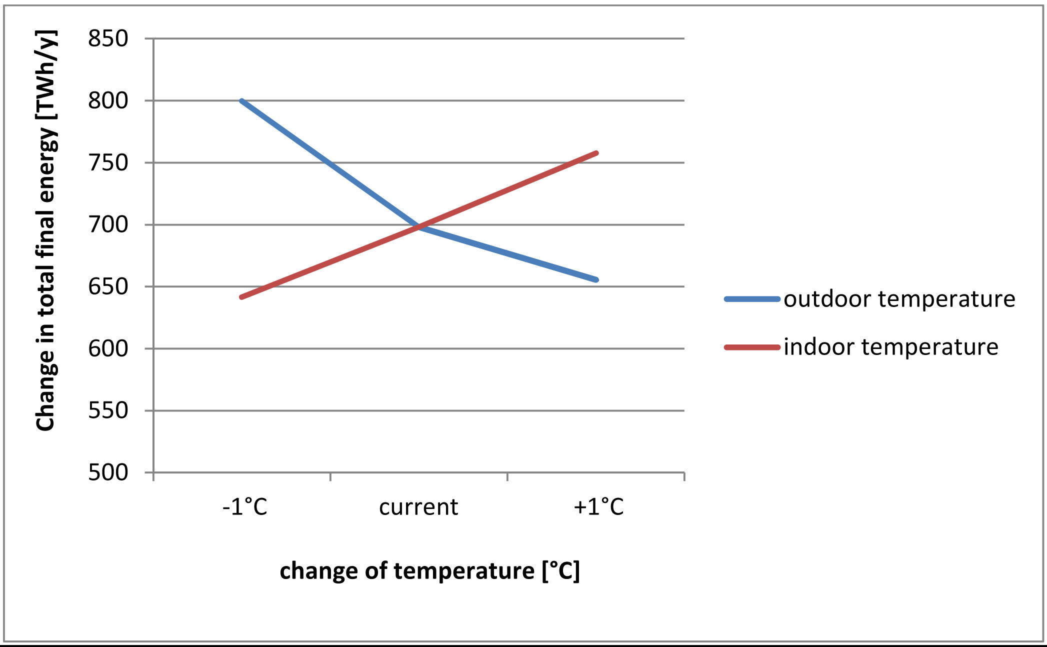

Figure 34: The absolute indoor and outdoor temperatures (final energy) obtained from the sensitivity analysis

- Modification of the U-values

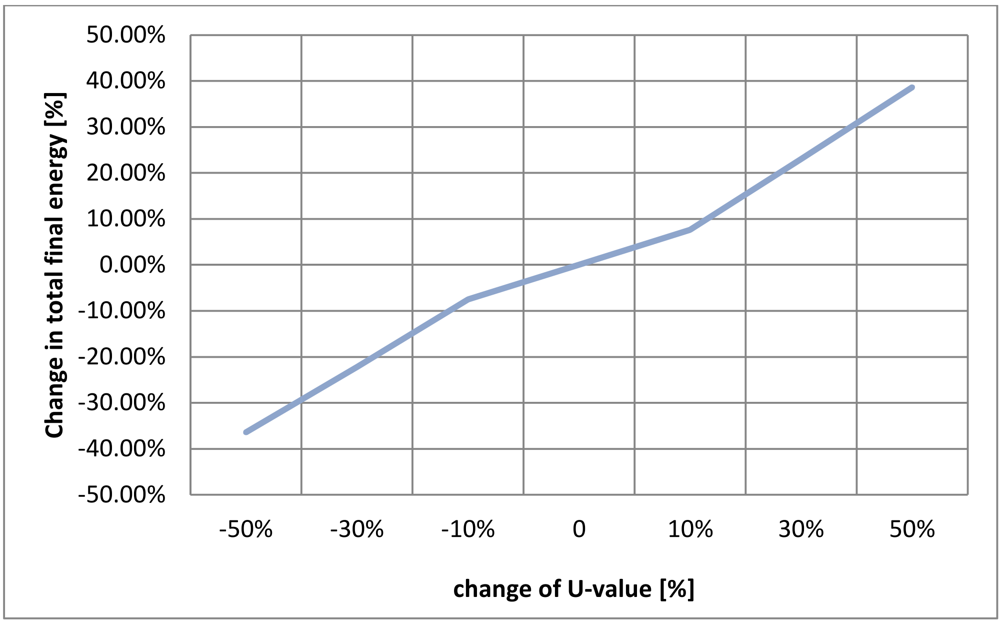

Figure 35: Change of the U-values in total final energy (relative values)

U-value	-50%	-30%	-10%	0,00%	10%	30%	50%
Final energy [TWh/y]	-36.41%	-22.21%	-7.50%	0.00%	7.59%	22.98%	38.62%

Table 34: Relative changes of the U-values in final energy demand by changing the U-values from -50% to 50%

As mentioned in the previous subsection, by modifying the U-values the highest potential of energy savings are available. Thereby, in Table 34 and Table 35 the detailed final energy demands are listed in relation to the modification of the U-values. Furthermore, to abate the CO_2 emissions, the current German government is planning to force the owner of older dwellings to renovate their houses (49). This law is a part of the EnEV 2012 and will force house owners to retrofit their properties starting from 2020. That is supposed to be mainly reached by reducing the U-values (49). Therefore, the alteration of U-values up till - 30 % and saving around 150 TWh/y might become a realistic scenario in the near future.

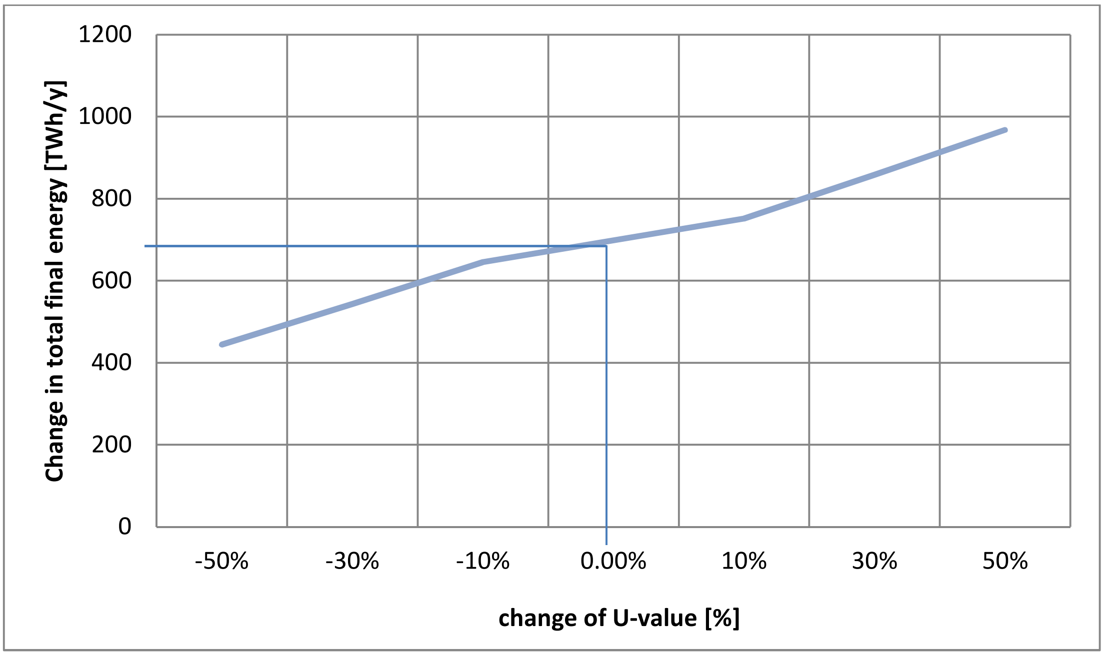

Figure 36: Change of the U-value in total final energy (absolute values)

U-value	-50%	-30%	-10%	0,00%	10%	30%	50%
Final energy [TWh/y]	443.87	542.96	645.60	697.98	750.94	858.37	967.54

Table 35: Absolute changes of the U-values in final energy demand by changing the U-values from -50% to 50%

Final energy [TWh/y]		
	Average U-values of all type of buildings	Average U-values of buildings erected 2002-2009
Heating	560.66	258.78
Hot water	59.85	59.85
Total	697.98	396.10

Table 36: Possible energy saving potential if all buildings would fulfil the U-values for buildings which were erected after 2002

In Table 36 the final energy demands, for hot water and heating in connection with the U-values, are depicted.

With the current average U-values of all buildings the heating final energy consumption accounts for 560.66 TWh/y. In the case that every dwelling would be renovated and would achieve U-values which were representative for buildings which were erected from 2002 till 2009, a heating final energy demand of 258.78 TWh/h would be reached – a drop of 300 TWh/y. That means, by changing the U-values of all the buildings to actual standards, the heating demand could decrease up to 54 % from 496.10 TWh/y to 228.98 TWh/y (Figure 37). Additionally, the total energy demand would abate up to 43.25 % from 697.98 TWh/y to 396.10 TWh/y (Figure 38)The hot water demands are not influenced by the U-values (Table 36), thus, there are no changes observable.

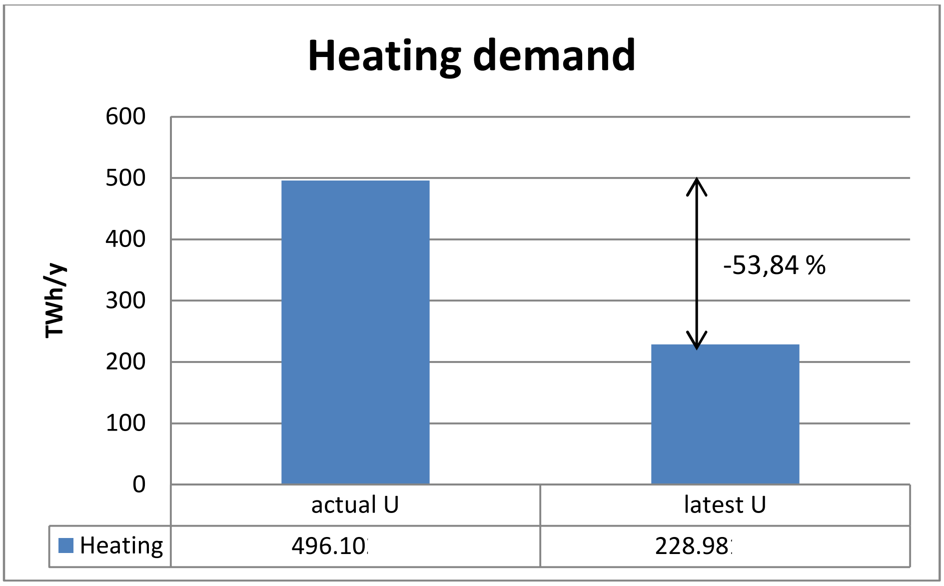

Figure 37: Potertial of saving heating demand by upgrading all residential buildings to the latest U-valeus

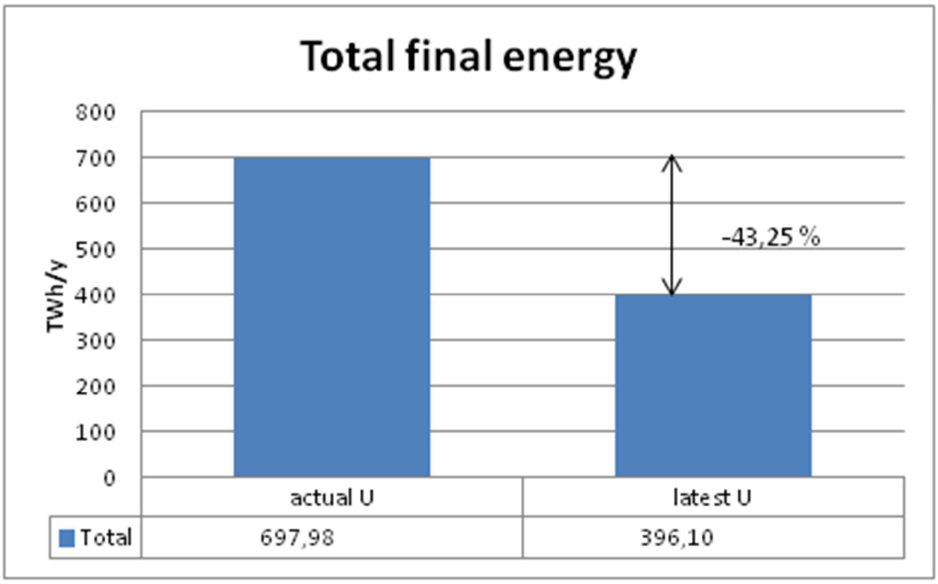

Figure 38: Potential of saving final energy deman by upgrading all residential buildings to the latest U-valeus

- Modification of the V_c-values

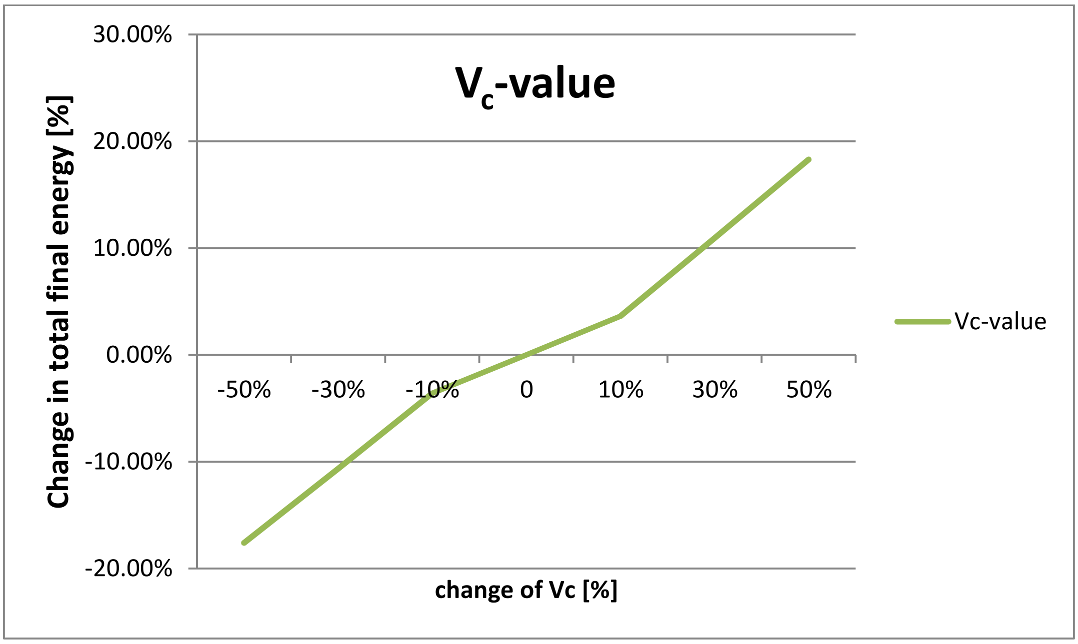

Figure 39: Changes of the Vc-value in total final energy (relative values)

The V_c-values provide the second biggest energy saving potential. Modest modifications of the V_c-values (+/- 10 %) cause only small changes of the energy consumption (around 3 % less final energy demands) (Figure 39). Thus, to gain reasonable savings greater efforts have to be made. In Germany the range of Vc-value is from 0.6 to 0.85. In general older buildings have higher V_c-values (due to infiror insulation), thus, also higher heat ventilation losses. By retroffiing older buildings the V_c-value can be reduced to 0.6. For instance, a hypothetical reduction of 50 % leads to a final energy demand of 575.08 TWh/y instead of 697.98 TWh/y (Figure 40). A complete table can be found in Appendix 7.

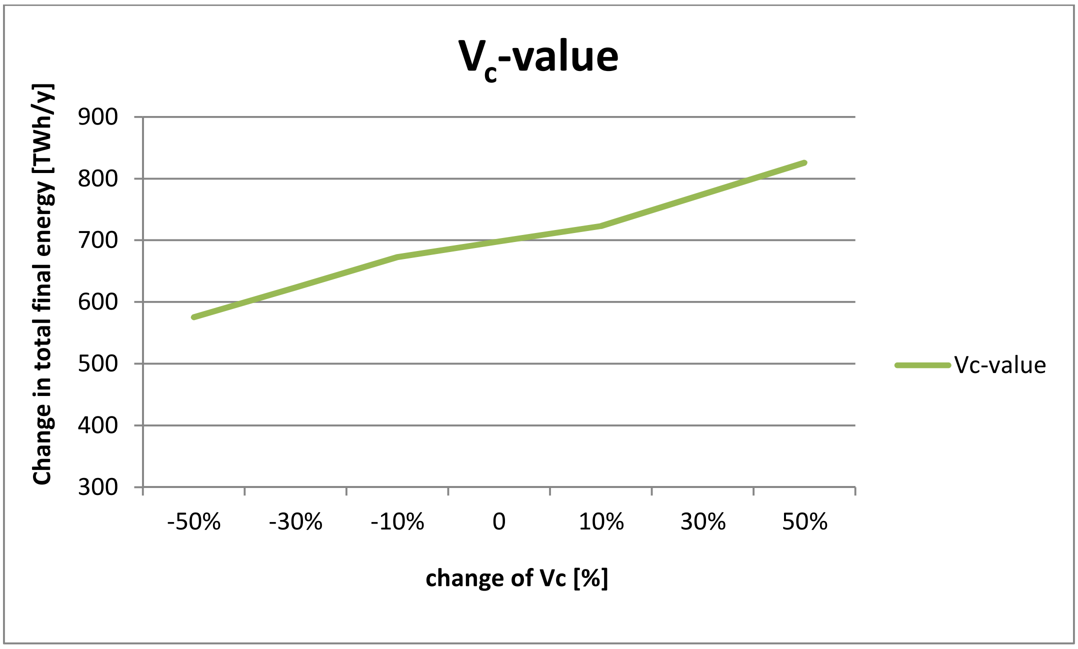

Figure 40: Changes of the Vc-value in total final energy (absolute values)

<u>Other parameters:</u>

Since the other physical parameters are not showing huge energy saving potentials, there are no detailed illustration and explanation in this report. Nonetheless, in Appendix 6 uncommented tables and graphs of the sensitivity analysis of some of the other conducted parameters are presented.

7.3 Normalized Sensitivity Analysis

Taking the normalized sensitivity analysis as a reference it is apparent that the average U-value, the total external surfaces of the building (S), the minimum outdoor temperature (Trmin), the heated floor area (A), the shading coefficient of the window (W_f) and the sanitary ventilation flow rate (V_c) play the most important role. The results are depicted in detail in Table 37.

primary input parameter	shorthead symbol	Unit	initial set value for the input parameter *(kj)*	initial output value in [tWh/a]	overall change in the input parameter *(2Δkj)*	overall change in the output variable (change in *yi in [tWh/a])*	sensitivity coefficient $\frac{\partial y_i}{\partial k_i}$	normalized sensitivity coefficient (Sij)
Total window surface	Sw	[m²]	61.25	697.98	1.23	-2.75	-2.24	-0.1967
Shading coefficient of the window	Wc	[%]	0.92	697.98	0.02	-9.94	-540.35	-0.7120
Frame coefficient of the window	Wf	[%]	0.70	697.98	0.01	-2.75	-196.12	-0.1967
Coefficient of solar transmission of the window	Ts	[%]	0.74	697.98	0.01	-2.75	-186.15	-0.1967
Average constant heat gain due to people in the building	Oc	[W/m²]	1.17	697.98	0.02	-0.51	-21.60	-0.0363
Effective volumetric heat capacity of a heated space (whole building)	TC	[J/K]	189358482.65	697.98	3787169.65	-0.22	0.00	-0.0157
Indoor temperature above which opening windows/natural ventilation is assumed to occur	Tv	[°C]	24.00	697.98	0.48	-0.04	-0.08	-0.0027
Maximum indoor temperature	Tmax	[°C]	25.00	697.98	0.50	0.00	0.00	0.000137

Natural ventilation flow rate	Vcn	[l/s/m2]	8.80	697.98	0.18	0.00	0.00	-0.000042
Electricity consumption of hydro pumps	Hyp	[W/m²]	0.40	697.98	0.01	0.23	28.70	0.0164
Average constant heat gain due to appliances in the building	Ac	[W/m²]	1.87	697.98	0.04	0.37	9.95	0.0267
Sanitary ventilation flow rate	Vc	[l/s/m$^{2]}$	0.79	697.98	0.02	5.02	317.14	0.3599
Average power demand for hot water production	Hw	[W/m²]	1.44	697.98	0.03	1.20	41.64	0.0859
Average constant heat gain due to lighting in the building	Lc	[W/m²]	0.28	697.98	0.01	0.05	8.78	0.0035
Area of heated floor space	A	[m²]	189.23	697.98	3.78	6.37	1.68	0.4566
Total external surfaces of the building	S	[m²]	271.67	697.98	5.43	10.55	1.94	0.7556
Average U-value of the building envelope	U	[W/m²K]	1.22	697.98	0.02	10.55	433.58	0.7556
Minimum indoor temperature	Tmin	[°C]	18.00	697.98	0.36	-21.25	-59.03	-1.5222

Table 37: Tabele with the normalized sensitivity analysis

8. Discussion and conclusion

8.1 Discussion

Regarding the EABS model a high consistency can be certified, inasmuch appropriate results were calculated, which were very close to the output values of the compared databases Eurostat, ‘stat. Bundesamt’, and Ministry of Economics:

Space heating demand calculated with the EABS model (reference year 2009):

560.66 TWh/y

Deviation for the space heating demand compared to the databases:

-1.3 % till 14 %

Total final energy demand calculated with the EABS model (reference year 2009):

697.98 TWh/y

Deviation for the total final energy demand compared to the databases:

1.3 % till 9.6 %

Depending on the several sources, which were used to compare the final energy demands, the simulated heating and energy demand vary slightly up to a moderate level (-1.3 % to 14 %). Possible causes for the deviation are discussed and listed in this section. In addition, other uncertainties and unsteadiness are mentioned in the following pages:

- The databases of the Ministry of Economics, Eurostat, and ‘stat. Bundesamt’ provide different output values. Unfortunately, it was not mentioned how the several databases calculated the energy demands for the reference year 2009. Besides, no information about the used building classification was given. Thus, no reasonable statements about the deviations can be made.
  Moreover, in this thesis the focus was on the space heating demand. For these values a multitude of parameters were considered since they have the biggest impact on the energy demand, whereas for hot water (H_w) or appliances (A_c) only one or a few characteristic values were regarded. Hence, it could be possible that the values for hot water or appliances do not show the same constancy than the parameters for space heating.

- Since the indoor and outdoor temperatures were also considered in the EABS simulation, the amount of buildings in the several climate zones in Germany had to be determined. Therefore, various assumptions were made to establish the three climate areas including the number of residential buildings in each zone. (see chapter 3.2). In addition, the version of the software Meteonorm, which was used for the thesis, provided only climate data up till 1990. That means that the change of the outdoor temperatures over the last 20 years have not been taking into account. It follows, the amount of buildings are representing the year 2009 while the corresponding data for the climate are usually from 1990 or earlier.

  Furthermore, neither the IWU nor other sources could provide information about the effective volumetric heat capacity values (TC). For this purpose the TC-values for each building type had to be ascertained, while at the same time some simplifications for the heating capacity of the buildings were set (see chapter 3.2).

  These two arrangements might also be a possible reason for the moderate deviations for the space heating demand compared to the databases 'stat. Bundesamt' and the Ministry of Economy.

- The individual influence of the tenants cannot be covered in the simulation. The constant gain due to people in the building (O_c) or the constant consumption of the appliances (A_c), and some other parameter are mean values and were often simplified. Since the most people have different consumption habits the EABS simulation can only provide a general overview, for which reason simplified and average values were used.

  In addition, the values which consider the impact of the tenants were not explicitly investigated for each construction period or climate zone, because often not enough reliable information were available. For instance, it was assumed that the hot water demand (T_c) had for all MFDs the same values independent of the year of construction and the belonging climate zone.

- For the building classification IWU 2011 combined the APs and HHs into one category (11). To provide as accurate as possible results in this thesis these two types of housing were spilt up. By calculating and combing a reasonable number of AP and HH buildings could be established from several sources (13) (9) (11) (8). Nonetheless, the exact amount of HHs and APs remained uncertain, since some assumptions were made. Due to the relative high energy demand for APs and HHs modifications in the amount of buildings can lead to minor (up to moderate) deviations for the output values.

- By considering the building occupancy for 2009 more accurate output values could be simulated. One the one side, by calculating the total heating demand, and assuming at the same time building occupancy of 100 % for all type of buildings, a 25 % higher value was determined. On the other side, by neglecting unoccupied houses (i.e. just considering occupied houses) a more reasonable value of 560.66 TWh/y was resulted. For simplification it was assumed that each of the 122 reference building was occupied by around 95 % (see chapter 3.3), since no further information were available to obtain a more accurate data concerning the building occupancy of the various reference buildings.

Furthermore, as stated in chapter 1 a limitation regarding the non-residential building appeared:

- In this report the investigation for the energy demands was limited to residential buildings. Regarding commercial or industrial buildings (offices, restaurants, recreational facilities etc.) many physical parameters values could be extracted on TWW 2012, while for the quantification no data were available (June 2012). Therefore, non-residential buildings could not take into account (see also next subsection). Even for the residential buildings in Germany the distribution after the amount and all (!) type of buildings was published for the first time in 2011 (11). From this it follows that a simulation of the energy demands for commercial buildings may be conducted if sufficient data about the amount of non-residential constructions in the different states/regions/climate zones is presented.

8.2 Conclusion

A successful archetype of buildings representing the German residential building stock could be defined: In total 122 reference buildings were established, consisting of five housing categories, up to ten different periods of construction, and three climate zones.

The sensitivity analysis proved that the U-values (heat transfer coefficient of the buildings) and the sanitary ventilation rate (V_c) affect the total final energy consumption of the German building stock the most. Further research regarding those values might be necessary. Beyond that, the hot water demand influences the total final energy changes moderately, while other parameters play a secondary role.
For instance, the TC-value, considering the German building stock, is hardly relevant compared to the Spanish building stock (21), since Germany has lower mean outdoor temperatures, which are further from the desired internal temperatures.
→ Altering U-values by – 50 % may lower the total final energy demand up to 40 %.
Moreover, if all existing residential buildings would fulfill the U-values listed in the EnEV 2009 the heating demand might decrease up to 53 %.
The V_c-values provide a saving potential of 18 % of the total final energy demand in 2009.

Besides, the outdoor and indoor temperatures were also taken into account for the sensitivity analysis, where it came out that temperatures/climate conditions are affecting the total final energy demand in a moderately-high way.
→ Due to the influence of the temperatures changes up to 15 % were measured.

Concerning the results from the EABS model the rehabilitation seems to be a reasonable measurement, especially for 'Plattenbausiedlungen' and houses which were built before the introduction of the 'WärmeschutzV' in the late 1970s, to fulfill several national and international requirements to reduce the greenhouse gas emissions and the energy consumption. But for verification of the stated measurements above, further simulations are necessary to assess the opportunity of retrofitting the German building stock. For instance, energy efficiency measures may be applied to this representation/building archetype to get a deeper insight into the energy saving potentials of the residential building stock of Germany.

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Appendix

Appendix 1: Regarding section 3.2 (c):

Determination of the amount of buildings in each German state and climate zone:

Compared to the data from IWU 2010 (since not the same reference year as in this report the total amount of building is slightly lower) the following numbers were derived:

Amount of Buildings	100%	17,954,932
North Germany	38.1%	6840829.09
East Germany	17.60%	3160068.03
South	44.30%	7954034.88

Appendix 1: From IWU 2010

	State	Population		Total Population	Fraction	%	Number of buildings	Total
North	S.Holstein+Hamburg	4,606,359	31,030,512	81,745,468	**37.96%**	5.64	**1011761**	17,954,932
	N.sachsen+Bremen	8,578,999				10.5	**1884329**	
	Nordrhein-Westfalen	17,845,154				21.83	**3919588**	
East	Mecklenburg-Vorpommern	1,642,327	16,334,047		**19.98%**	2	**360728**	
	Sachsen-Anhalt	2,335,006				2.86	**512871**	
	Brandenburg+Berlin	5,972,212				7.31	**1311763**	
	Sachsen	4,149,477				5.07	**911409**	
	Thühringen	2,235,025				2.73	**490911**	
South	Baveria	12,538,696	34,380,909		**42.06%**	15.34	**2754054**	
	Baden-Wuerttemberg	10,753,880				13.16	**2362029**	
	Saarland	1,017,567				1.24	**223503**	
	Rheinland-Pfalz	4,003,745				4.9	**879400**	
	Hessen	6,067,021				7.42	**1332587**	

Appendix 2: Determination of the number of buildings in each state. The calculated fraction shows high consistency with the values from IWU 2010.

The table above leads to the following number of buildings in each climate zone:

Climate zone	State	Number of Buildings		Fraction
A	S.Holstein+Hamburg	1011760.83	8371767	0.47
	N.sachsen+Bremen	1884328.85		
	Nordrhein-Westfalen	3919587.65		
	Hessen	1332587.02		
	Saarland	223502.86		
B	Baden-Württemberg	2362029.22	5917702	0.33
	Rheinland-Pfalz	879400.06		
	Thüringen	490910.66		
	Brandenburg+Berlin	1311762.76		
	Sachsen-Anhalt	512870.93		
	Mecklenburg-Vorpommern	360727.88		
C	Bayern	2754054.01	3665463	0.20
	Sachsen	911409.27		

B(NBL)	0.25
C(NBL)	0.75

Appendix 3: Share and number of buildings in each climate zone. NBL = Neue Bundeslaender (= reunified states after 1990)

Appendix 2: Regarding section 3.4:

List of the 122 reference buildings used in this investigation:

Number of building		Determination of the buildings after		
Building no.	**Building_ID**	**Climate zone**	**Age of construcion**	**Type of dwelling**
1	110	A	till 1918	SFD/TFD
2	111	A	till 1918 framework	SFD/TFD
3	112	A	1919-1948	SFD/TFD
4	113	A	1949-1957	SFD/TFD
5	114	A	1958-1968	SFD/TFD
6	115	A	1969-1978	SFD/TFD
7	116	A	1979-1983	SFD/TFD
8	117	A	1984-1994	SFD/TFD
9	118	A	1995-2001	SFD/TFD
10	119	A	2002-2009	SFD/TFD
11	120	A	till 1918	RH
12	122	A	1919-1948	RH
13	123	A	1949-1957	RH
14	124	A	1958-1968	RH
15	125	A	1969-1978	RH
16	126	A	1979-1983	RH
17	127	A	1984-1994	RH
18	128	A	1995-2001	RH
19	129	A	2002-2009	RH
20	130	A	till 1918	MFD
21	131	A	till 1918 framework	MFD
22	132	A	1919-1948	MFD
23	133	A	1949-1957	MFD
24	134	A	1958-1968	MFD
25	135	A	1969-1978	MFD
26	136	A	1979-1983	MFD
27	137	A	1984-1994	MFD
28	138	A	1995-2001	MFD
29	139	A	2002-2009	MFD
		A	1946-1960	MFD NBL
		A	1961-1969	MFD NBL
30	140	A	till 1918	AP(apartm. Block)
31	142	A	1919-1948	AP(apartm. Block)
32	143	A	1949-1957	AP(apartm. Block)
33	144	A	1958-1968	AP(apartm. Block)
34	145	A	1969-1978	AP(apartm. Block)
		A	1979-1983	AP(apartm. Block)
		A	1984-1994	AP(apartm. Block)

		A	1970-1980	AP(apartm. Block) NBL
		A	1981-1985	AP(apartm. Block) NBL
		A	1986-1990	AP(apartm. Block) NBL
35	154	A	1958-1968	HH
36	155	A	1969-1978	HH
		A	1970-1980	HH NBL
		A	1981-1985	HH NBL
37	210	B	till 1918	SFD/TFD
38	211	B	till 1918 framework	SFD/TFD
39	212	B	1919-1948	SFD/TFD
40	213	B	1949-1957	SFD/TFD
41	214	B	1958-1968	SFD/TFD
42	215	B	1969-1978	SFD/TFD
43	216	B	1979-1983	SFD/TFD
44	217	B	1984-1994	SFD/TFD
45	218	B	1995-2001	SFD/TFD
46	219	B	2002-2009	SFD/TFD
47	220	B	till 1918	RH
48	222	B	1919-1948	RH
49	223	B	1949-1957	RH
50	224	B	1958-1968	RH
51	225	B	1969-1978	RH
52	226	B	1979-1983	RH
53	227	B	1984-1994	RH
54	228	B	1995-2001	RH
55	229	B	2002-2009	RH
56	230	B	till 1918	MFD
57	231	B	till 1918 framework	MFD
58	232	B	1919-1948	MFD
59	233	B	1949-1957	MFD
60	234	B	1958-1968	MFD
61	235	B	1969-1978	MFD
62	236	B	1979-1983	MFD
63	237	B	1984-1994	MFD
64	238	B	1995-2001	MFD
65	239	B	2002-2009	MFD
66	2310	B	1946-1960	MFD NBL
67	2311	B	1961-1969	MFD NBL
68	240	B	till 1918	AP(apartm. Block)
69	242	B	1919-1948	AP(apartm. Block)
70	243	B	1949-1957	AP(apartm. Block)
71	244	B	1958-1968	AP(apartm. Block)
72	245	B	1969-1978	AP(apartm. Block)
		B	1979-1983	AP(apartm. Block)

		B	1984-1994	AP(apartm. Block)
73	2410	B	1970-1980	AP(apartm. Block) NBL
74	2411	B	1981-1985	AP(apartm. Block) NBL
75	2412	B	1986-1990	AP(apartm. Block) NBL
76	254	B	1958-1968	HH
77	255	B	1969-1978	HH
78	2510	B	1970-1980	HH NBL
79	2511	B	1981-1985	HH NBL
80	310	C	till 1918	SFD/TFD
81	311	C	till 1918 framework	SFD/TFD
82	312	C	1919-1948	SFD/TFD
83	313	C	1949-1957	SFD/TFD
84	314	C	1958-1968	SFD/TFD
85	315	C	1969-1978	SFD/TFD
86	316	C	1979-1983	SFD/TFD
87	317	C	1984-1994	SFD/TFD
88	318	C	1995-2001	SFD/TFD
89	319	C	2002-2009	SFD/TFD
90	320	C	till 1918	RH
91	322	C	1919-1948	RH
92	323	C	1949-1957	RH
93	324	C	1958-1968	RH
94	325	C	1969-1978	RH
95	326	C	1979-1983	RH
96	327	C	1984-1994	RH
97	328	C	1995-2001	RH
98	329	C	2002-2009	RH
99	330	C	till 1918	MFD
100	331	C	till 1918 framework	MFD
101	332	C	1919-1948	MFD
102	333	C	1949-1957	MFD
103	334	C	1958-1968	MFD
104	335	C	1969-1978	MFD
105	336	C	1979-1983	MFD
106	337	C	1984-1994	MFD
107	338	C	1995-2001	MFD
108	339	C	2002-2009	MFD
109	3310	C	1946-1960	MFD NBL
110	3311	C	1961-1969	MFD NBL
111	340	C	till 1918	AP(apartm. Block)
112	342	C	1919-1948	AP(apartm. Block)
113	343	C	1949-1957	AP(apartm. Block)
114	344	C	1958-1968	AP(apartm. Block)
115	345	C	1969-1978	AP(apartm. Block)

		C	1979-1983	AP(apartm. Block)
		C	1984-1994	AP(apartm. Block)
116	3410	C	1970-1980	AP(apartm. Block) NBL
117	3411	C	1981-1985	AP(apartm. Block) NBL
118	3412	C	1986-1990	AP(apartm. Block) NBL
119	354	C	1958-1968	HH
120	355	C	1969-1978	HH
121	3510	C	1970-1980	HH NBL
122	3511	C	1981-1985	HH NBL

Appendix 3: Regarding Section 4:

Heated Floor Area:

Building no.	Building_ID	Heated Floor Area in m^2
1	110	149.038
2	111	137.873
3	112	135.156
4	113	138.043
5	114	139.837
6	115	144.898
7	116	148
8	117	142.307
9	118	140.74
10	119	144.303
11	120	122.857
12	122	113.75
13	123	118.75
14	124	113.43
15	125	120
16	126	123.684
17	127	122.222
18	128	124
19	129	123.333
20	130	294.737
21	131	260
22	132	291.304
23	133	335.897
24	134	358.182
25	135	340.624
26	136	431.25
27	137	361.945
28	138	595
29	139	585.714
30	140	1000
31	142	1700
32	143	1033.33
33	144	1400
34	145	1667
35	154	1400
36	155	1667
37	210	149.038
38	211	137.873
39	212	135.156
40	213	138.043

41	214	139.837
42	215	144.898
43	216	148
44	217	142.307
45	218	140.74
46	219	144.303
47	220	122.857
48	222	113.75
49	223	118.75
50	224	113.43
51	225	120
52	226	123.684
53	227	122.222
54	228	124
55	229	123.333
56	230	294.737
57	231	260
58	232	291.304
59	233	335.897
60	234	358.182
61	235	340.624
62	236	431.25
63	237	361.945
64	238	595
65	239	585.714
66	2310	335.897
67	2311	358.182
68	240	1000
69	242	1700
70	243	1033.33
71	244	1400
72	245	1667
73	2410	1667
74	2411	1667
75	2412	1667
76	254	1400
77	255	1667
78	2510	1667
79	2511	1667
80	310	149.038
81	311	137.873
82	312	135.156
83	313	138.043
84	314	139.837

85	315	144.898
86	316	148
87	317	142.307
88	318	140.74
89	319	144.303
90	320	122.857
91	322	113.75
92	323	118.75
93	324	113.43
94	325	120
95	326	123.684
96	327	122.222
97	328	124
98	329	123.333
99	330	294.737
100	331	260
101	332	291.304
102	333	335.897
103	334	358.182
104	335	340.624
105	336	431.25
106	337	361.945
107	338	595
108	339	585.714
109	3310	335.897
110	3311	358.182
111	340	1000
112	342	1700
113	343	1033.33
114	344	1400
115	345	1667
116	3410	1667
117	3411	1667
118	3412	1667
119	354	1400
120	355	1667
121	3510	1667
122	3511	1667

Red values: Mean value from IWU 2011 for GMH erected from 1969 till 1994

Green values: Overtaken from regular MFDs built from 1958 till 1968

Appendix 4: Regarding Section 4: TC-value

Material of the exterior/interior wall and ceiling/floor and determing the TC-value

Typology	Material	d (m)	roh (kg/m³)	Cp(J/kgK)	TC/A (layer)	TC/S	average
till 1918 framework							
exterior/interior wall	view timber with clay	0.1	1000	1000	100000	100000	
ceilling/floor	plank (Diele)	0.025	415	2720	28220		
	fill(sand or clay)	0.075	1200	917	82530	110750	
till 1918							
exterior/interior wall	plaster(putz)	0.01	1300	1000	13000		
	Solid brick masonry (Vollziegelmauerwerk)	0.09	1400	836	105336	118336	
ceilling/floor	plank(Diele)	0.025	415	2720	28220		
	fill(sand or clay)	0.075	1200	917	82530	110750	
1919-1948							
exterior/interior wall	plaster(Putz)	0.01	1300	1000	13000		
	Solid brick masonry (Vollziegelmauerwerk)	0.09	1400	836	105336	118336	
ceilling/floor	plank(diele)	0.025	415	2720	28220		
	fill(sand)	0.075	1600	835	100200	128420	
1949-1957							
exterior/interior wall	masonry of pumice(Mauerwerk aus Bimsbeton)	0.1	1000	1050	105000	105000	
ceilling/floor	floating floor screed(schwimmender Estrich)	0.045	2000	1000	90000		
	insulation(rock wool)	0.02	30	840	504		
	reinforced concrete	0.035	2000	1000	70000	160504	
1958-1968							
exterior/interior wall	masonry of pumice(mauerwerk aus bimsbeton)	0.1	1000	1050	105000	105000	
ceilling/floor	floating floor screed(schwimmender Estrich)	0.045	2000	1000	90000		
	insulation(rock wool)	0.02	30	840	504		
	reinforced concrete(Stahlbeton)	0.035	2000	1000	70000	160504	

1969-1978							
exterior/interior wall	Plaster	0.01	1300	1000	13000		
	hollow brick (Hochlochziegel)	0.09	1400	1000	126000	**139000**	
ceilling/floor	floating floor screed(schwimmender Estrich)	0.045	2000	1000	90000		
	insulation(Polystyrol)	0.02	1050	840	17640		
	reinforced concrete(stahlbeton)	0.035	2000	1000	70000	**177640**	
1979-1983					0		
exterior/interior wall	lime sand brick(Kalksandstein)	0.02	2100	1000	42000		
	beton	0.03	2000	1000	60000		
	insulation(facade insulation)	0.05	100	1000	5000	**107000**	
or	Plaster	0.01	1300	1000	13000		
	hollow brick (Hochlochziegel)	0.09	1400	1000	126000	**139000**	**123000**
ceilling/floor	floating floor screed(schwimmender Estrich)	0.04	2000	1000	80000		
	insulation(Polystyrol)	0.06	1050	840	52920	**132920**	
1984-today	assumption: predominantly exterior insulation						
exterior/interior wall	Plaster	0.01	1300	1000	13000	**13000**	
or	Plaster	0.01	1300	1000	13000		
	hollow brick (Hochlochziegel)	0.09	1400	1000	126000	**139000**	
or	Plaster	0.01	1300	1000	13000		
	cellular concrete(porenbeton)	0.09	500	1050	47250	**60250**	**70750**
ceilling/floor	floating floor screed(schwimmender Estrich)	0.04	2000	1000	80000		
	insulation(Polystyrol)	0.06	1050	840	52920	**132920**	

Age of construcion	Type of dwelling	S_floor	S_ceiling	TC/S(floor/ceiling)	88%	S_interior walls	S_fassade	TC/S(fassade/interior walls)	TC
till 1918	SFD/TFD	128.9	128.9	110750	0.875	232.02	196.04	118336	75774218.32
till 1918 framework	SFD/TFD	199	199	110750	0.875	358.2	171.78	100000	92599000.00
1919-1948	SFD/TFD	275	275	128420	0.875	495	237.3	118336	149966412.80
1949-1957	SFD/TFD	101	101	160504	0.875	181.8	119.8	105000	61703683.00
1958-1968	SFD/TFD	242	242	160504	0.875	435.6	185.33	105000	137164336.00
1969-1978	SFD/TFD	157.5	157.5	177640	0.875	283.5	170.55	139000	114143737.50
1979-1983	SFD/TFD	196	196	132920	0.875	352.8	161.4	123000	109926940.00
1984-1994	SFD/TFD	136.55	136.55	132920	0.875	245.79	213.3	133750	93594437.94
1995-2001	SFD/TFD	110.8	110.8	132920	0.875	199.44	128.6	133750	69996034.50
2002-2006 /2009	SFD/TFD	133.2	133.2	132920	0.875	239.76	190.86	133750	88996825.50
till 1918	RH	87.24	87.24	110750	0.875	157.032	76.47	118336	44632535.33
1919-1948	RH	102.5	102.5	128420	0.875	184.5	66.14	118336	53256711.04
1949-1957	RH	136	136	160504	0.875	244.8	136.66	105000	80497388.00
1958-1968	RH	106.7	106.7	160504	0.875	192.06	42.42	105000	56351166.10
1969-1978	RH	96.642	96.642	177640	0.875	173.9556	55.72	139000	63237399.61
1979-1983	RH	98.43	98.43	132920	0.875	177.174	56.1	123000	52135282.95
1984-1994	RH	116	116	132920	0.875	208.8	52.9	133750	62348940.00
1995-2001	RH	135.3	135.3	132920	0.875	243.54	45.2	133750	70515442.63
2002-2006	RH	138.1	138.1	132920	0.875	248.58	142.7	133750	84890257.13
till 1918	MFD	284	284	110750	0.875	511.2	148	118336	133351420.80
till 1918 framework	MFD	615.901	615.901	110750	0.875	1108.6218	629.13	100000	296339479.00
1919-1948	MFD	350	350	128420	0.875	630	325.54	118336	193649821.44
1949-1957	MFD	574.8	574.8	160504	0.875	1034.64	464	105000	328292948.40
1958-1968	MFD	2844.61	2844.61	160504	0.875	5120.298	2041	105000	1597874945.63
1969-1978	MFD	426.01	426.01	177640	0.875	766.818	338	139000	291599072.05
1979-1983	MFD	594.5	594.5	132920	0.875	1070.1	449.13	123000	328454382.50

1984-1994	MFD	707.4	707.4	132920	0.875	1273.32	776.8	133750	440970447.25
1995-2001	MFD	759	759	132920	0.875	1366.2	697.8	133750	454991403.75
2002-2006	MFD	1991	1991	132920	0.875	3583.8	1700	133750	1176079033.75
1946-1960	MFD NBL	1753	1753	160504	0.875	3155.4	1160.16	105000	974446199.00
1961-1969	MFD NBL	2493	2493	160504	0.875	4487.4	1482.48	105000	1368213219.00
till 1918	AP(apartm. Block)	754	754	110750	0.875	1357.2	307.4	118336	343917403.20
1919-1948	AP(apartm. Block)	1349.11	1349.11	128420	0.875	2428.398	1246	118336	745398110.91
1949-1957	AP(apartm. Block)	1457	1457	160504	0.875	2622.6	1378	105000	853350031.00
1958-1968	AP(apartm. Block)	3534	3534	160504	0.875	6361.2	3249.79	105000	2060105472.00
1969-1978	AP(apartm. Block)	3020	3020	177640	0.875	5436	2132	139000	2030447100.00
1970-1980	AP(apartm. Block) NBL	2825	2825	177640	0.875	5085	1601.73	139000	1844769595.00
1981-1985	AP(apartm. Block) NBL	2825	2825	132920	0.875	5085	1675.73	123000	1504385915.00
1986-1990	AP(apartm. Block) NBL	2825	2825	132920	0.875	5085	1675.73	133750	1570230793.75
1958-1968	HH	10408	10408	160504	0.875	18734.4	5579.16	105000	5648086064.00
1969-1978	HH	18012	18012	177640	0.875	32421.6	10093.9	139000	11745632560.00
1970-1980	HH NBL	4796	4796	177640	0.875	8632.8	2994.09	139000	3170065690.00
1981-1985	HH NBL	7270	7270	132920	0.875	13086	4223.74	123000	3860557570.00

The reason why the values have also be multiplied with 88% is mentioned in the main text in section 4.

Appendix 5: Regarding section 5:

Amount of buildings for each building reference:

Age of construcion	Type of dwelling	weight (buildings) IWU 2011	changed/adjusted after IWU 2011
till 1918	SFD/TFD	1040000	1040000
till 1918 framework	SFD/TFD	370000	370000
1919-1948	SFD/TFD	1280000	1280000
1949-1957	SFD/TFD	920000	920000
1958-1968	SFD/TFD	1580000	1580000
1969-1978	SFD/TFD	1470000	1470000
1979-1983	SFD/TFD	750000	750000
1984-1994	SFD/TFD	1040000	1040000
1995-2001	SFD/TFD	1080000	1080000
2002-2009	SFD/TFD	790000	790000
till 1918	RH	350000	350000
1919-1948	RH	800000	800000
1949-1957	RH	480000	480000
1958-1968	RH	670000	670000
1969-1978	RH	650000	650000
1979-1983	RH	380000	380000
1984-1994	RH	540000	540000
1995-2001	RH	500000	500000
2002-2009	RH	300000	300000
till 1918	MFD	380000	380000
till 1918 framework	MFD	50000	50000
1919-1948	MFD	460000	460000
1949-1957	MFD	390000	369437
1958-1968	MFD	550000	537250
1969-1978	MFD	320000	320000
1979-1983	MFD	160000	160000
1984-1994	MFD	210000	210000
1995-2001	MFD	200000	200000
2002-2009	MFD	70000	70000
1946-1960	MFD NBL		20563
1961-1969	MFD NBL		12750
till 1918	AP(apartm. Block)	10000	10000
1919-1948	AP(apartm. Block)	10000	10000
1949-1957	AP(apartm. Block)	30000	30000
1958-1968	AP(apartm. Block)	60000	58952

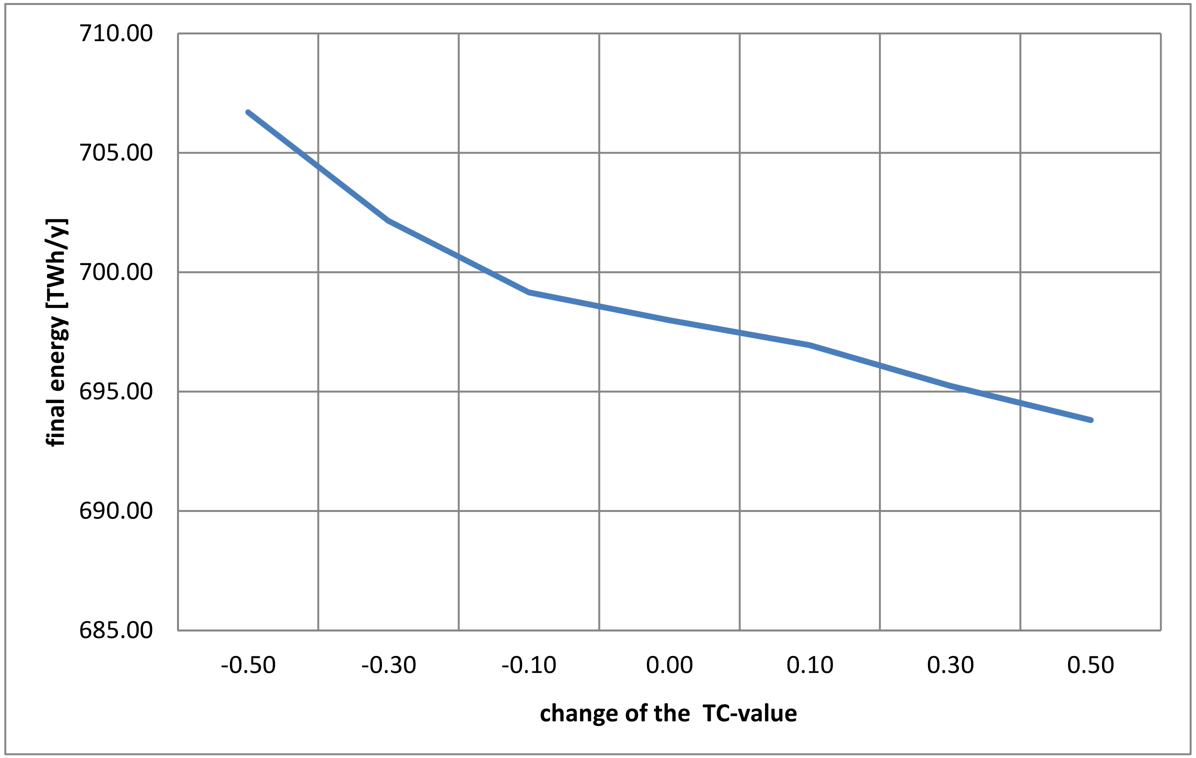
1969-1978	AP(apartm. Block)	80000	55220
1979-1983	AP(apartm. Block)	30000	14953
1984-1994	AP(apartm. Block)	40000	27292
1970-1980	AP(apartm. Block) NBL		16250
1981-1985	AP(apartm. Block) NBL		14000
1986-1990	AP(apartm. Block) NBL		12708
1958-1968	HH		1048
1969-1978	HH		780
1970-1980	HH NBL		7750
1981-1985	HH NBL		1047

Appendix 6: Regarding section 7:

Sensitivity Analysis: Values and graphs of the TC-value, hot water, and Ac-value

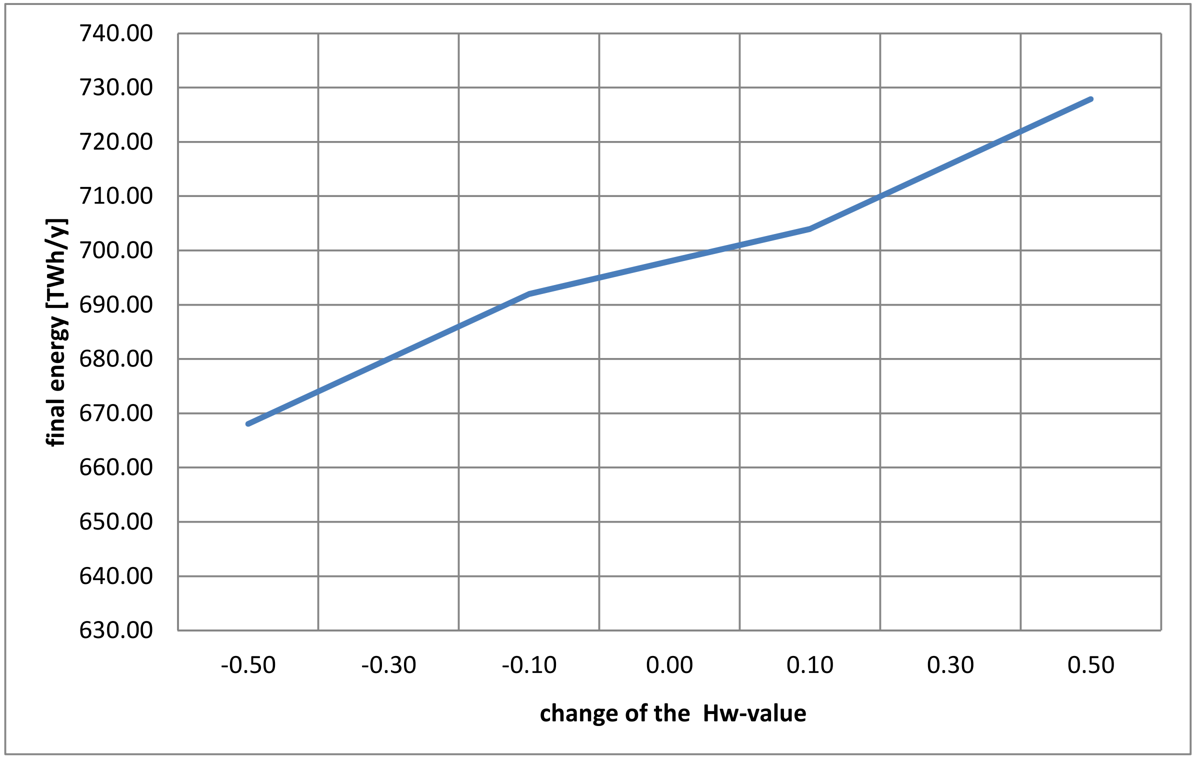
TC-value:

	useful energy TWh/y						
Tc	-50%	-30%	-10%	0	10%	30%	50%
Heating	503.810719	499.777905	497.143138	496.102833	495.188238	493.675524	492.410343
Lightening	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138
appliances	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957
hot water	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958
hydro pumps	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713
Total	633.576217	629.542101	626.906839	625.868598	624.953168	623.440785	622.176347
	final energy TWh/y						
Heating	569.369089	564.811505	561.833889	560.658214	559.624608	557.915051	556.485239
hot water	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729
Total	706.69342	702.135836	699.15822	697.982546	696.948939	695.239383	693.809571
Tc-value	-50%	-30%	-10%	0	10%	30%	50%
final energy TWh/y	706.69342	702.135836	699.15822	697.982546	696.948939	695.239383	693.809571


710.00
705.00
700.00
695.00
690.00
685.00
final energy [TWh/y]
-0.50
-0.30
-0.10
0.00
0.10
0.30
0.50
change of the TC-value

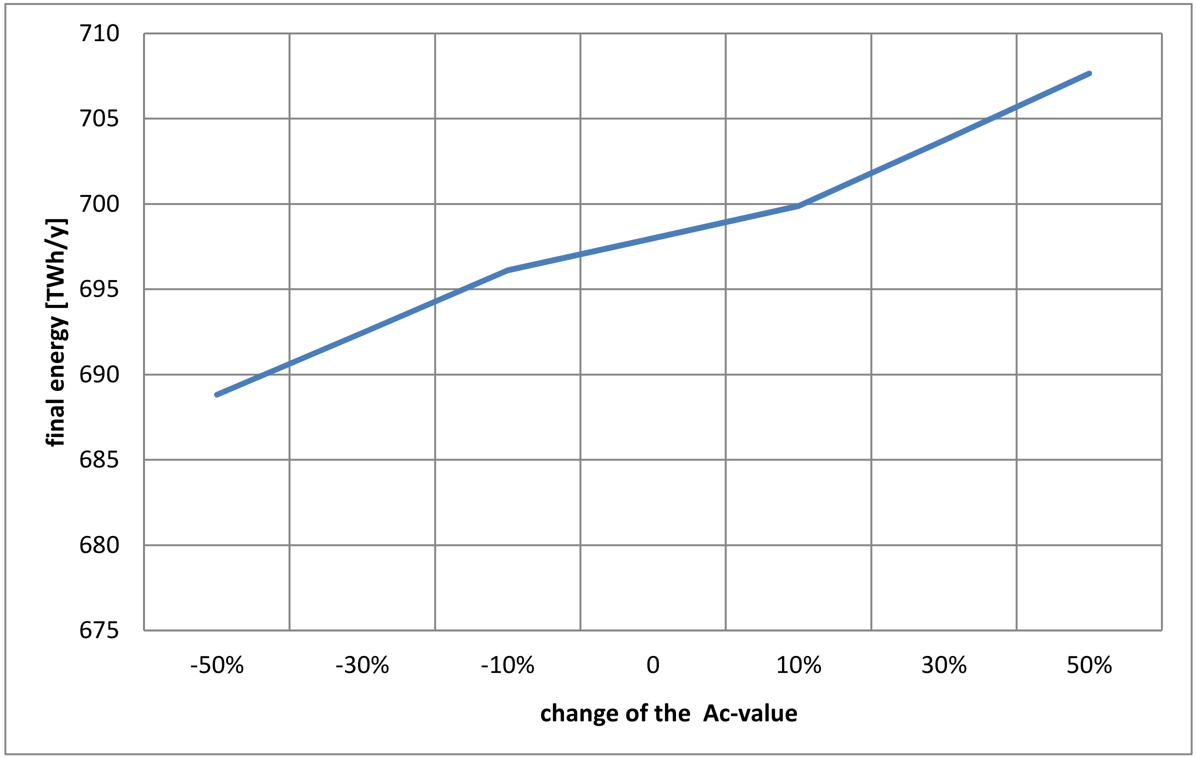
Hot water:

	useful energy TWh/y						
Hw	-50%	-30%	-10%	0	10%	30%	50%
Heating	496.102833	496.102833	496.102833	496.102833	496.102833	496.102833	496.102833
Lightening	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138
appliances	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957
hot water	26.1471541	36.605579	47.0640224	52.2922958	57.5224088	67.9831233	78.4407053
hydro pumps	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713
Total	599.721774	610.180488	620.639203	625.86856	631.097917	641.556632	652.015346
	final energy TWh/y						
Heating	560.658214	560.658214	560.658214	560.658214	560.658214	560.658214	560.658214
hot water	29.9277382	41.8983336	53.8689501	59.8531729	65.8395015	77.8127175	89.782348
Total	668.057111	680.027706	691.998323	697.982546	703.968874	715.94209	727.911721
Hw-value	-50%	-30%	-10%	0	10%	30%	50%
final energy TWh/y	668.057111	680.027706	691.998323	697.982546	703.968874	715.94209	727.911721


740.00
730.00
720.00
710.00
700.00
690.00
680.00
670.00
660.00
650.00
640.00
630.00
final energy [TWh/y]
-0.50
-0.30
-0.10
0.00
0.10
0.30
0.50
change of the Hw-value

Ac-value:

	useful energy TWh/y						
Ac	-50%	-30%	-10%	0	10%	30%	50%
Heating	513.672124	506.599037	499.586085	496.102833	492.641459	485.763056	478.952898
Lightening	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138
appliances	29.0350751	40.6489423	52.2618899	58.0697957	63.8756613	75.491837	87.1063843
hot water	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958
hydro pumps	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713
Total	614.400966	618.942637	623.543614	625.86856	628.212906	632.949224	637.752857
	final energy TWh/y						
Heating	580.513709	572.520237	564.594724	560.658214	556.746429	548.972974	541.276644
hot water	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729
Total	688.80332	692.423715	696.11115	697.982546	699.876626	703.719346	707.637564
Ac-value	-50%	-30%	-10%	0	10%	30%	50%
final energy TWh/y	688.80332	692.423715	696.11115	697.982546	699.876626	703.719346	707.637564


710
705
700
695
690
685
680
675
final energy [TWh/y]
-50%
-30%
-10%
0
10%
30%
50%
change of the Ac-value

Appendix 7: Regarding section 7:

U-value and VC-value:

Table for U-values (graph see section 7):

	useful energy TWh/y						
U-value	-50%	-30%	-10%	0	10%	30%	50%
Heating	271.2502945	358.931633	449.759455	496.102833	542.961063	638.024289	734.623685
Lightening	7.943091376	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138
appliances	58.06979574	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957
hot water	52.29229577	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958
hydro pumps	11.45827129	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713
Total	401.0137872	488.695729	579.524061	625.868598	672.724947	767.789509	864.388834
	final energy TWh/y						
Heating	306.5467391	405.637611	508.284404	560.658214	613.613871	721.0472	830.216592
hot water	59.85317292	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729
Total	443.8710705	542.961943	645.608736	697.982546	750.938202	858.371531	967.540923
U-value	-50%	-30%	-10%	0.00%	10%	30%	50%
final energy TWh/y	443.8710705	542.961943	645.608736	697.982546	750.938202	858.371531	967.540923
	-36.41%	-22.21%	-7.50%	0.00%	7.59%	22.98%	38.62%

Table for Vc-values (graph see section 7):

	useful energy TWh/y						
Vc	-50%	-30%	-10%	0	10%	30%	50%
Heating	387.356627	430.200051	473.952538	496.102833	518.414417	563.448119	608.989065
Lightening	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138	7.94309138
appliances	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957	58.0697957
hot water	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958	52.2922958
hydro pumps	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713	11.4582713
Total	517.121653	559.965654	603.717436	625.86856	648.179497	693.213044	738.755775
	final energy TWh/y						
Heating	437.761408	486.179833	535.625612	560.658214	585.873093	636.766806	688.233767
hot water	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729	59.8531729
Total	575.085739	623.504164	672.949943	697.982546	723.197425	774.091137	825.558098
Vc-value	-50%	-30%	-10%	0	10%	30%	50%
final energy TWh/y	575.085739	623.504164	672.949943	697.982546	723.197425	774.091137	825.558098