Master Thesis

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zum Thema

“An approach to model the thermal demand of buildings“

A case study using two districts of Graz

vorgelegt von

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Science Pledge

Hereby I, Stefan Mayer, declare that this master thesis was written without the help of a third party and without the use of sources other than the ones cited in this paper. In addition, I certify that all thoughts in this paper that are not my own writing, including images, figures and tables, are appropriately referenced.

Vienna, 30.6.2014
(Place, Date) (Stefan Mayer)

Kurzfassung

In dieser Arbeit wird die Modellierung des jährlichen Wärme- und Kühlbedarfs für Gebäude am Beispiel zweier Grazer Bezirke gezeigt. Das Hauptziel ist die Erfassung der Bedarfsstruktur in verschiedenen Stadtteilen sowie eine mögliche Lokalisierung der Bedarfsschwerpunkte. Die Bestimmung des Wärme- und Kühlbedarfs von Gebäuden erfolgt im Wesentlichen über die Berechnung der individuellen Energiebilanz einzelner Gebäude. Für die praktische Umsetzung der entsprechenden Bedarfsberechnung wird die Programmiersprache Python verwendet. Thermale Gewinne und Verluste können einzeln und in Kombination aus beiden berechnet werden. Diese Master Thesis zeigt detailliert, welche Einflüsse bei der Bestimmung des Wärme- und Kühlbedarfs von Gebäuden zu berücksichtigen sind. Somit werden einerseits qualitative und quantitative Aussagen über die Gebäudequalität und die Bedarfsstruktur getroffen, andererseits wird auch das Zusammenspiel von Gebäudegeometrie, -alter und -typ aufgezeigt. Weiters wird der wesentliche Einfluss klimatischer Bedingungen hervorgehoben.

Die präsentierte Methode könnte mit einem verbesserten Gebäudemodell oder einer höheren zeitlichen Auflösung bei der Berechnungsmethode optimiert werden. Mit der Berücksichtigung des Warmwasserbedarfs sowie von Heiz-, Lüftungs- und Kühlsystem kann auch der Endenergiebedarf berechnet werden.

Abstract

The current paper deals with an approach to model the annual heating and cooling demand of buildings, using two districts of the city of Graz as case study. Hence, the main objective is to gather the demand patterns within different parts of the city and to localise demand hotspots. A determination of the heating and cooling demand of buildings is carried out via the calculation of the heat balance of individual buildings. The practical implementation consists of the generation of a building model and the proper demand calculation, which is performed via the Python programming language. Thermal gains and losses of buildings are calculated separately. This master thesis shows in detail which kind of effects have to be considered when determining the heating and cooling demand of buildings. While qualitative and quantitative statements can be made about the building quality and the demand patterns, the interactions of building geometry, age and type are also revealed. Moreover, the significant influence of climatic conditions is highlighted.

The approach chosen for this paper could be enhanced by considering an advanced building model or a higher level of temporal resolution. By considering the warm water heating demand and the integration of the HVAC-system into the model, the final thermal energy demand can be calculated.

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1. INTRODUCTION

1.1. Motivation

The report from the European Environmental Agency about “Urban sprawl in Europe” (EEA, 2006) points out that more than a quarter of the European Union's territory is directly affected by urban land use. Moreover, approximately 80 % of the Europeans will be living in urban areas by 2020, in some countries the share will be around 90 %. Hence, urban energy planning and management have become more and more important.

Nowadays, the challenge for cities lies in the development of strategies to reduce greenhouse gases (GHG) and to increase the energy efficiency. In order to comply with the Kyoto Protocol and to implement the standards claimed by the European Union, cities and especially urban planning processes have to concentrate on optimizing energy supply chains and to increase the use of low carbon energy. Therefore, it would be very helpful to know where energy demand hotspots are located within a city, or how energy supply chains could be optimized to save energy transfer losses or transportation costs.

The potentials for implementing efficient strategies are available, as in cities a lot of individual measures can be obtained in different sectors like: energy production, energy networks, energy-efficient buildings but also urban design, transport, water and waste. Until now, all different elements have not been implemented in an integrated system, which helps to understand the city as a complex framework with interacting components and all its consequential processes, due to governmental barriers.

This thesis can be seen as a starting point towards an energy mapping tool, which tries to find an appropriate method to visualize the thermal energy demand for cities or city districts, by considering the demand of buildings only.

1.2. Objectives – Research Questions

The main objective is the mapping of the overall heating and cooling demand of buildings in order to assess potentials for energy saving measures and planning optimization as well as to point out supply scenarios. Therefore, the focus of this master thesis is to establish a GIS-based environment to model the thermal energy demand within the building sector of city quarters or even cities.

The process contains data acquisition and manipulation processes of different data sources like building, energy or statistical data as well as the integration of these data sources within a GIS. Hence, the first step is to investigate and compare different GIS-based methods, followed by the development of a feasible methodology, which shall be applicable for different case studies. In order to achieve plausible results, an evaluation of the final outcome will be necessary.

The focus of this thesis will be placed on the spatial distribution of thermal demand within urban areas and various demographic structures. The final representation of the thermal energy demand will be anonymized through raster (125x125m). At least two different case studies will be considered in order to validate and evaluate the results of the chosen method. These conditions prompt some research questions, which should be answered at the end of this thesis:

- What is the spatial distribution of the thermal demand for residential and non-residential buildings within city quarters and what are the main differences between these diverse usage types?

- Is it possible to identify thermal hotspots in the specified area?

- Is it possible to spot the mostly affected energy-consuming building types? When were those buildings constructed?

- Does the chosen model provide a scalable and transferable picture of relevant information to perform realistic energy demand scenarios for residential buildings?

- How can relevant influences and parameters be ideally linked to obtain a quantitative evaluation of the thermal demand?

- Which input parameters are mandatory and are they sufficiently available?

1.3. Solution Approach

Modeling the thermal demand for cities or city districts requires some basic information. Starting at the building level, relevant properties and attributes have to be allocated with building footprints. Altogether, with the building height or storeys, it is possible to calculate the gross floor area, which is the key value for further calculations.

Still, the specific heating demand of a building depends on various building properties, whereas some of them are more or less mandatory and some are optional, depending on the applied method and the desired accuracy level. For example, a building age and building type matrix could be used to assign specific heating demand values to building classes. There should also be a distinction between residential and non-residential buildings, as various approaches use different sub-models to calculate and visualize the energy demand. There exists a variety of different approaches using different data sources, which are described in *Chapter* 2 "*Literature Review*".

1.4. Expected Results

The main goal is to visualize the thermal demand, in particular for heating and cooling, which is ideally anonymized through raster presentation with 125m solution. If possible, data from local energy suppliers will be used to evaluate the results. An integration of statistical data could help to verify and confirm the results. Finally, the answer of the following questions will approve a positive evaluation of the used method.

- What is the spatial distribution of the thermal energy demand for residential and non-residential buildings?
- Is it possible to identify thermal hotspots within the specified area?
- How can relevant influences and parameters be linked to obtain a quantitative evaluation of the energy demand?
- Are the results comparable with realistic values and what is the difference between residential and non-residential buildings, regarding to the range of the specific heating demand?

1.5. Demarcation

First of all, it is not the scope of this master thesis to develop a demand mapping tool. Moreover, it is not its purpose to find the “solitary” method for modeling the thermal energy demand. This thesis does not cover the subject of final energy, which depends on heating system and energy carrier. Speaking about thermal demand does not include the topics hot water, electrical appliances, heat pumps or air conditions. Additionally, it is not part of the scope to cover the transportation or mobility sector with its energy demand in cities. The evaluation of renewable energy resources or analyzing different types of energy carrier is also not in the scope of this thesis.

1.6. Target Audience

This thesis will be valuable for everyone who is familiar with GIS (Geographical Information System) or interested in urban energy planning issues. It is not necessary to have a specific background in one of these fields, as the thesis tries to lead through the topic. Above all, questions about different GIS-based energy demand modeling methods will be demonstrated. As this thesis should establish a sustainable basis for urban energy planning processes, it might be relevant for everyone dealing with urban planning questions. Thus, the reader should have an affinity to these topics, but also people interested are invited to read this script.

1.7. Structure

The master thesis opens up with the “*Introduction*” part, followed by the chapter “*Literature Review*” to present the actual state of the art of this topic. Furthermore, it will be clarified why some methods are important but not used for the thesis and the advantages and disadvantages of each method will be outlined. Beside this, possibilities to combine or to extend different methods will be explained.

First of all, in the main part of the thesis the theoretical demand calculation in the “*Method*” section is presented, which mainly deals with the energy balance of individual buildings. The chapter “*Project Description*” contains the practical implementation of the applied method. Subsequently, *Chapter* 5 “*Results*” describes all outcomes for the heating and cooling demand, which will be examined according to their severity and plausibility in the “*Discussion*” part of the thesis.

Finally, the content of this master thesis is completed by the “*Conclusion*” section. In *Figure 1* the whole structure of the master thesis is illustrated.

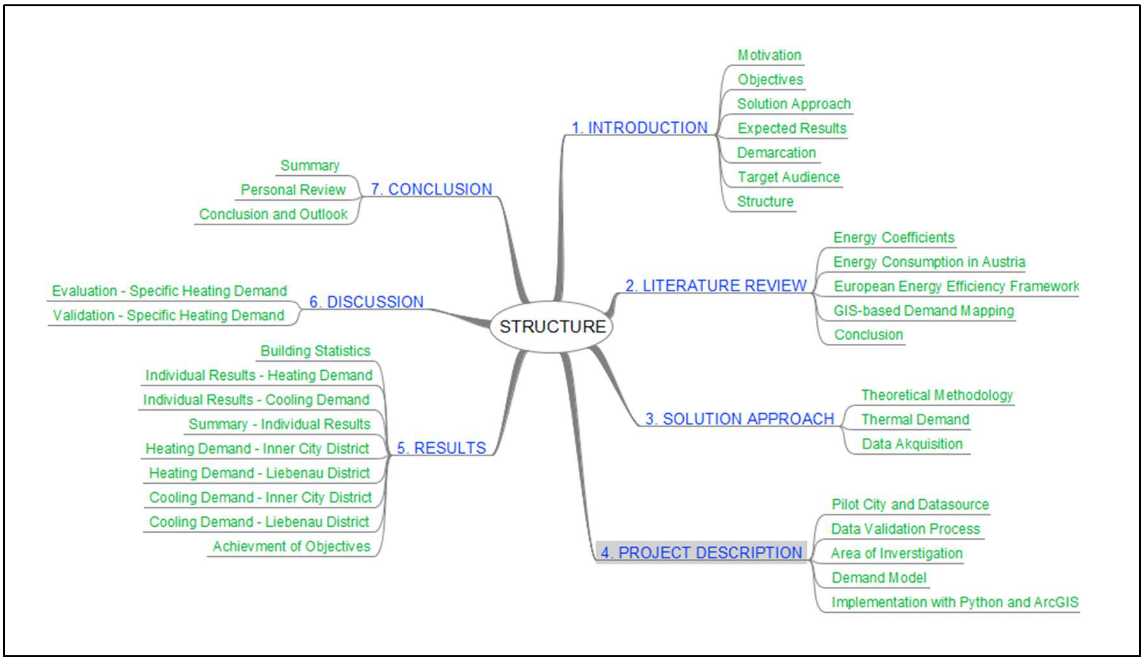


Figure 1: Structure of the Master Thesis

2. LITERATURE REVIEW

As described in the introduction chapter, cities of today are facing problems due to increasing GHG emissions, increasing energy prices and an increasing population. After short definitions of the most important energy coefficients, some statistics about the energy consumption will underline these facts at the beginning of this chapter. Subsequently, a look at the European energy efficiency framework will be depicted, trying to cut primary energy consumption of European countries by 20% until 2020. All stages of the energy chain will be considered, whereas public transport and the building sector will represent the greatest saving potentials in the near future. The most relevant policies concerning thermal energy demand for buildings, including their implementation in Austria, will be presented ahead of the key issue.

The main purpose of this thesis is to show how the usage of GIS can help to localize thermal demand hotspots and demand patterns of cities, in order to generate a decision support system optimizing the planning processes subsequently. Therefore, different GIS-based approaches of thermal energy demand mapping should lead to a feasible method afterwards. First of all, some 2-dimensional approaches will be presented, followed by 3D-GIS methods. Finally, a conclusion of these approaches used in different countries introduces the "*Method*" chapter.

2.1. Energy Coefficients

Conventionally, it has to be distinguished between primary and secondary energy products and between renewable and non-renewable products in the energy field. The following definitions show the essential difference between primary and secondary energy.

"Primary energy is energy embodied in sources which involve human induced extraction or capture, that may include separation from contiguous matrial, cleaning or grading, to make the energy available for trade, use or transformation" (Øvergaard, 2008)

"Secondary energy is energy embodied in commodities that comes from human induced energy transformation" (Øvergaard, 2008)

The gross energy consumption is, by definition of EUROSTAT (2013), the total energy demand of a country and covers the energy consumption by energy sector itself, all distribution or transport losses and final energy consumption by end user. This also includes the transformation output such as electricity or heat produced by other energy sources. Subsequently, the gross energy consumption is calculated as:

primary production + recovered products + net imports + variations of stocks – bunkers

The final energy consumption is the total energy consumption by the end user, which reaches the end user´s door (EUROSTAT, 2013). End users are industries, agriculture, services, transport or private households. Final energy does not include energy used by the energy sector and energy delivering or transformation losses.

Sometimes it is necessary to compare the energy consumption of different sectors, like transportation and building sector, or just two buildings or dwelling units. So, it is essential to use the same metric unit. A gigajoule (GJ) for example, is a unit into which energy consumption from different sources can be converted. One GJ is equivalent to 277.8 kWh of electricity or 26.86 m^3 natural gas. A measure of energy intensity is one GJ/m^2, which can be used to represent the annual energy consumption for room heating or hot water. The additional "*per square meter*" shows that this is a spatial indicator, which describes where energy is consumed in space. Hence, it is possible to map the energy use on different scales, like building, neighborhood or community scale (WEBSTER, 2009).

Reading energy statistics can sometimes be very confusing, also because most of the available statistics use different measures. The following statistics and measures use Petajoule PJ ($= 10^{15}$J; 1 PJ ≈ 278 GWh) and Gigajoule GJ ($= 10^{9}$J; 1 GJ ≈ 278 kWh).

2.2. Energy Consumption in Austria

This part will provide you with an overview about the energy consumption in Austria and its socio-economic impact by starting with the gross national energy and the final energy consumption per year. A breakdown of the final energy consumption per sector leads to the structural analysis with the most affected usage groups and to the thermal energy demand of the Austrian households. Reading this section should point out the enormous energy consumption within the building and private sector.

2.2.1. Gross and Final Energy Consumption

As illustrated in *Figure 2*, the gross national energy consumption (GNEC) of Austria has increased from nearly 800 PJ (Petajoule) in the year 1970 to more than 1.400 PJ in the year 2011, whereas the consumption has remained relatively constant since the year 2005. The same is valid for the trend of the final energy consumption (FEC), which constituted about 567 PJ in the year 1970 and rose to more than 1.000 PJ in the year 2011 (STATISTIK AUSTRIA, 2013a). The difference between the GNEC and the FEC is explicable via the amount of energy exports and the energy stock in Austria, which have to be subtracted from the GNEC. To get a clearer understanding of the consumption of this huge amount of energy, a breakdown by economic sectors will follow.

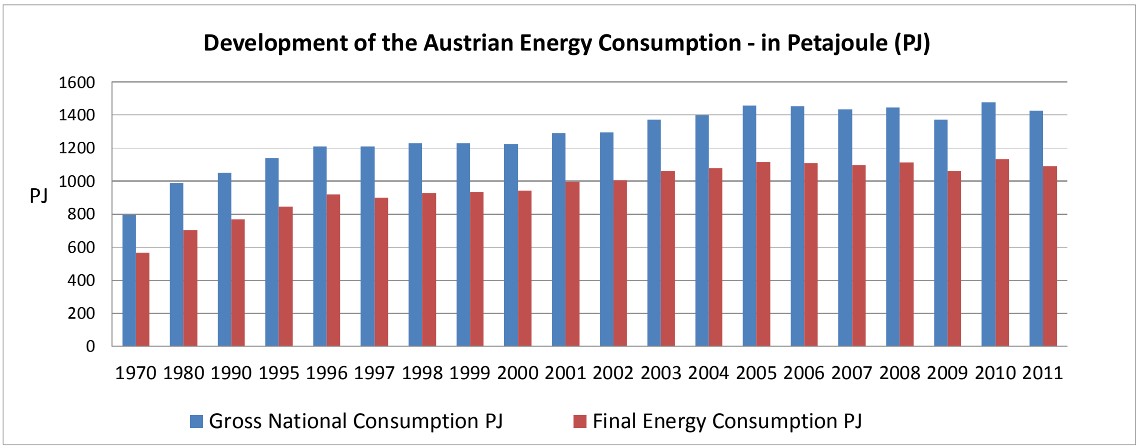


Figure 2: Development of the Austrian Energy Consumption (in PJ) from 1970 to 2011

(Source: STATISTIK AUSTRIA, 2013a)

2.2.2. Energy Consumption by Sector

The succeeding sector distribution in agriculture, production, transportation, services and private households is taken from STATISTIK AUSTRIA (2013a) data source. The development of FEC by sector in the year 1990 shows the private household sector in the first place, with a FEC of 300 PJ, measured after an increasing trend starting from the 1970´s. Since the year 1990, the amount of FEC in private households has remained steady, whereas the production and the transportation sector have increased strongly during the last decade. The maximum value of the transportation sector was measured in the year 2007 with more than 382 PJ.

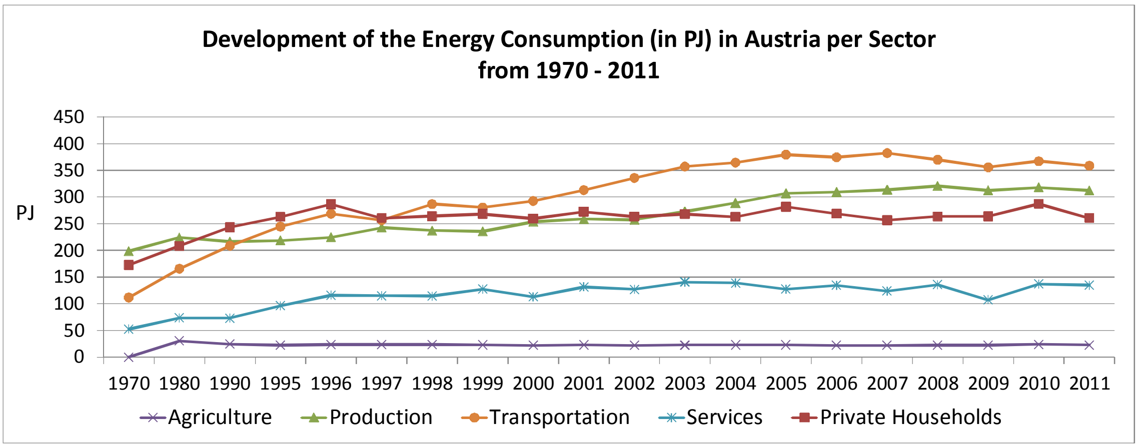


Figure 3: Development of the Austrian Energy Consumption (in PJ) per Sector from 1970 to 2011

(Source: STATISTIK AUSTRIA, 2013a)

The percentage of the FEC within the economic sectors is pictured in *Figure 4*. We see the transportation sector with 33%, the production sector with 29% and private households with 24% of the annual FEC in 2011. The service (12%) and agriculture (2%) sectors have a lower amount.

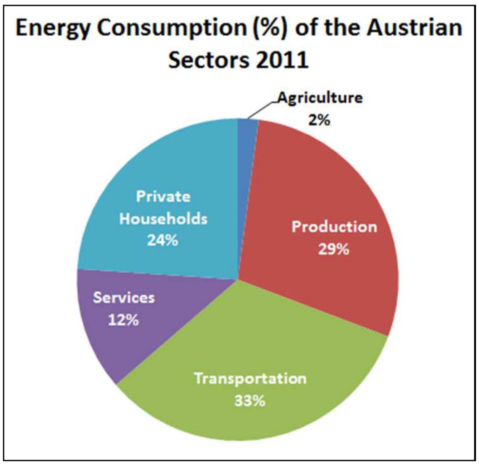


Figure 4: Austrian Energy Consumption (in %) per Sector in the Year 2011 (Source: STATISTIK AUSTRIA, 2013a)

2.2.3. Energy Consumption by Structural Usage

The final energy consumption classified by structural usage (STATISTIK AUSTRIA, 2013a) is presented in *Figure 5*. The usage through traffic and mobility (33%) is mainly influenced by fossil fuels and will not be analyzed any further. More than half of the final energy consumption is used for room heating (and cooling) or hot water (31%) and process heat (industrial furnace and steam generation, 22%), whereby the latter will not be taken into consideration because of a lack of data availability.

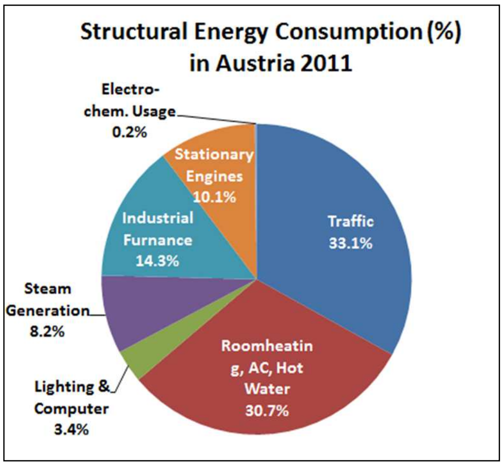


Figure 5: Structural Energy Consumption (in %) in the Year 2011 (Source: STATISTIK AUSTRIA, 2013a)

Hence, the room heating sector with 31% of the total final energy consumption in Austria is of special interest. The following tables provide us with information about the usage of energy carriers, the overall consumption measures including different benchmarks and monetary issues.

The energy usage for all households of the heating period 2009/2010 in Austria is separated in room heating, hot water cooking and electrical appliances. The greatest part of the energy conumption is used for room heating (~ 200 PJ, ~72%), the amount for hot water (~33 PJ, ~12%) and electrical appliances (~37 PJ, ~13%) and cooking (~7.5 PJ, ~3%) is clearly less. The sum of all categories is about 274 PJ, which does not sound very exciting, but Table 2 shows the total costs of these energy consumption values, which are about 6.7 Billion Euros (STATISTIK AUSTRIA, 2013a). So, with a saving potential of only 10% per year, it would be possible to save 670 Million Euros (compared to the 20% target initiative; EC, 2008).

Table 1: Austrian Energy Carrier by Usage (Households) 2009/2010 (source: STATISTIK AUSTRIA, 2013a)

ENERGY CARRIER	2009/2010				
	Room Heating (GJ)	Hot Water (GJ)	Cooking (GJ)	Electrical Appliances (GJ)	Sum (PJ)
Coal, Coke	1,936,743	116,492	17,467	-	2.07
Wood	50,417,900	3,050,799	494,736	-	53.96
Pellets, Holzbriketts	5,350,839	433,986	11,264	-	5.80
Wood chip	5,097,281	507,057	-	-	5.60
Heating oil	47,466,109	4,673,601	-	-	52.14
Liquid gas	1,520,754	240,023	34,527	-	1.80
Natural gas	48,118,527	7,508,464	730,103	-	56.36
District heating	22,802,092	4,471,567	-	-	27.27
Electricity	8,718,587	8,854,887	6,118,358	37,370,621	61.06
Solar heat	1,897,288	2,203,740	-	-	4.10
Heat pump	3,440,864	970,758	-	-	4.41
SUM	**196,766,986**	**33,031,373**	**7,406,455**	**37,370,621**	**274.58**
Percentage	71.76%	12.03%	2.70%	13.61%	100%

Looking at the benchmark results of the Austrian households from the heating period 2009/2010, there is an average consumption of 207 GJ per person and year, or 4.6 GJ/m². The average household consumes about 538.6 GJ per heating period. It is obvious that these are average values and that there are other relevant parameters and facts, which influence the energy consumption of buildings (e.g. building age, occupancy, personal behaviors, U-value, location …).

Table 2: Energy Carrier and Benchmarks 2009/2010 (source: STATISTIK AUSTRIA, 2013a)

ENERGY CARRIER	Benchmarks			Amount (GJ)				Euro (€)			
	Household (HH)	Usable area (m²)	Persons (P)	SUM	GJ/HH	GJ/m²	GJ/Pers.	SUM	€/HH	€/m²	€/Pers.
Coal, Coke	89,378	9,311,433	195,349	2,070,702	85	1	38	33,831,037	1,419	13	626
Wood	1,172,905	149,938,907	3,243,366	53,963,435	46	0	17	320,781,193	273	2	99
Pellets, wood briquettes	195,371	22,114,402	516,059	5,796,090	75	1	27	72,209,242	916	8	326
Wood chip	55,468	7,792,186	188,596	5,604,337	101	1	30	26,862,809	484	3	142
Heating oil	842,615	100,366,110	2,074,609	52,139,710	62	1	25	1,046,442,109	1,242	10	504
Liquid gas	51,729	6,335,883	139,218	1,795,304	35	0	13	54,029,494	1,044	9	388
Natural gas	1,096,507	105,448,250	2,375,971	56,357,094	51	1	24	993,405,926	906	9	418
District heating	849,683	66,082,198	1,744,465	27,273,659	32	0	16	1,101,145,496	1,296	17	631
Electricity	3,594,603	367,553,237	8,375,290	61,062,453	17	0	7	3,049,348,988	848	8	364
Solar heat	360,671	48,163,507	1,066,698	4,101,028	11	0	4	0	0	0	0
Heat pump	195,141	27,067,074	566,430	4,411,622	23	0	8	0	0	0	0
SUMME	8,504,071	910,173,186	20,486,050	274,575,434	539	5	207	6,698,056,293	8,429	79	3,499

A look at the Austrian energy consumption has pictured out an enormous energy saving potential especially for the private household sector, room heating and energy efficiency of buildings. Reality has shown the importance of arrangements in this sector, especially due to the fact that most of this energy is covered by fossil fuels. The next part of this thesis will demonstrate the role of the European Union trying to guide the European countries in terms of requirements for energy efficiency and saving potentials concerning buildings.

2.3. European Energy Efficiency Framework for Buildings

This sector points out how the energy consumption of European countries is guided through the European energy efficiency framework, which demands more energy efficiency, a higher usage of renewable energy and a reduction of CO_2 emissions to cut the primary energy consumption about 20% by the year 2020 (EC, 2008). For Austria, this means that the FEC should decrease with about 1.100 PJ (BMWFJ, 2010) on the level of the year 2005. So, what do European policies associated to thermal energy consumption and buildings claim from the members of the European Union?

2.3.1. Energy Efficiency Plan 2011

On 8th of March 2011, the European Commission published the "Energy Efficiency Plan 2011" for saving more energy through concrete measures aiming at households, businesses and public authorities. The focus of the EU´s Europe 2020 Strategy is laid on energy efficiency, with a transition to a resource-efficient economy with smart, sustainable and inclusive growth. The EC values energy efficiency as Europe´s biggest energy resource and the most cost-effective way to reduce GHG emissions and to enhance the security of energy supply (EC, 2011).

The energy efficiency measures cover an efficient use of natural resources and high standards of environmental protection. All existing and new measures should reduce the annual GHG emissions by 740 million tons, create up to 2 million jobs and generate annual financial savings of up to €1000 per household. As the greatest energy saving potential lies in buildings, the plan focuses on instruments to trigger the renovation process in public and private buildings. Furthermore, it aims at improving the energy performance of the components and appliances used in them. In this context, the communication of the EC also points out that about 40% of the final energy consumption comes from the building sector (houses, public and private offices, shops and other buildings), whereas residential homes use two thirds thereof for space heating. Methods exist to decrease the buildings' consumption by half or three quarters, but the renovation rate of buildings is too low (EC, 2011). The most important instrument for the

European building sector is the Directive of the European Parliament and of the Council on the performance of buildings.

2.3.2. Directive on the Energy Performance of Buildings (EU, 2010)

The expanding building sector accounts 40% of the EU's total energy consumption. Therefore, the European Union demands a reduction of the energy consumption, the use of renewable energy sources and a focus on energy efficiency. A key part of this legislation is the Energy Performance of Buildings Directive (EPBD).

The EPBD 2010/31/EU amends the EPBD 2002/91/EC, which was first published in 2002 and requires from all EU countries to enhance their building regulations and to introduce energy certification schemes for buildings. All countries were also required to have inspections of boilers and air-conditioners.

The Directive promotes the improvement of the energy performance of buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor climatic requirements and cost-effectiveness. It aims to promote the energy performance of buildings and building units. The Member States shall adopt a methodology for calculating the energy performance of buildings including certain elements:

- Thermal characteristics of a building (thermal capacity, insulation, etc.)
- Heating insulation and hot water supply
- Air-conditioning installation
- Built-in lighting installation
- Indoor climatic conditions

Further aspects like solar exposure, natural lighting and electricity produced by cogeneration and district or block heating, as well as cooling systems are also taken into account (EU, 2010). The implementation in Austria and its outcomes will be shown subsequently.

2.3.3. Implementation of the EPBD in Austria

It is a matter of fact that the main problems regarding energy efficiency improvements concern poor implementations of existing legislation, missing consumer awareness and no adequate structures to invest in energy efficient buildings, products or services (EC, 2008).

The implementation of the EPBD (2002/91/EC), based on building codes, regulations of the provinces and the "*Energieausweis-Vorlage-Gesetz* (EAV-G)" of Austria, was completed in 2008, after a difficult process of harmonization between the nine provinces, which had nine different building codes and different regulations concerning energy. A revision process in order to adapt the recast of the EPBD/ (2010/31/EU) is still in progress (EU, 2011). Beside others, the most important outcome of the EPBD in Austria is the implementation of a nationally harmonized certification system for buildings and the energy performance.

The certification of buildings has to be started from very different building codes of the provinces. In 2006, the process of harmonization and implementation was initiated, managed by the OIB (Austrian Institute of Construction Engineering) and official working group of representatives of the nine provinces. Most of the harmonized energy-relevant regulations came into force between January and May 2008.

The energy performance certificate assigns an energy performance label to residential and non-residential buildings or building units, which is only based on calculated values and has a validation of 10 years. This energy label classifies buildings on a scale range from A++ (high energy efficiency) to G (poor energy efficiency). An important content of the labeling is the specific heating demand in kWh/m²a. This energy label criteria will be relevant concerning building classification or further mapping issues (EU, 2011).

A++	<= 10	kWh/m²a
A+	<= 15	kWh/m²a
A	<= 25	kWh/m²a
B	<= 50	kWh/m²a
C	<=100	kWh/m²a
D	<=150	kWh/m²a
E	<=200	kWh/m²a
F	<=250	kWh/m²a
G	>=250	kWh/m²a

2.4. GIS-based Energy Demand Mapping

This section describes the state of the art of various approaches which allow the modeling of the thermal energy demand in order to locate hotspots or specific demand patterns within cities.

2.4.1. 2D Model Concept – Various Approaches

The first example, extracted from JONES (2001), presents an Energy and Environmental Prediction Model (EEP) for cities, which is based on GIS and consists of different sub-models. Two sub-models are of interest, which have a focus on the energy use for domestic and non-domestic buildings, as well as the level of required data and the survey methods. JONES (2001) also describes that it is not possible to gather all the essential information for every building of a city to deploy an entire data base. This is also mentioned by BIBERACHER (2010). Therefore, urban planning and GIS sometimes have to operate with relatively incomplete data.

As a domestic sub-model requires a lot of properties to be included, JONES (2001) uses a cluster analysis procedure to group properties with similar energy performance characteristics.

The individual properties creating clusters are “heated ground floor area”, “facade”, “window to wall ratio”, exposed end area” and “age”, which have, on behalf of JONES (2001), the greatest effect on the domestic energy performance. The basic unit to describe these properties is the postcode. Each property has its own position using the postcode, road name and number. Information about the heated ground floor, exposed end area, storey and facade area can be acquired via the building dimension in GIS. The age of the buildings was obtained from historical sources and arranged to five different groups.

The non-domestic energy sub-model considers commercial and public buildings with thirteen groups and forty-eight sub-groups, which also vary with the building type. Data sources to identify the type of property can be the local council database or site visits. Energy use by industrial processes is found in another sub-model and is determined by governmental energy supply or specific site statistics. Finally, it is important not to forget the traffic flow and the emission processes (JONES, 2001).

The approach from BIBERACHER (2010) shows the development of a model framework to analyse the energy demand within a specified region on a spatially and temporally highly disaggregated level. The framework contains three modules (potential, demand and dynamic), which are operating on a spatial level of 250m raster cells. For the temporal resolution, the author uses one month.

WEBSTER (2009) connects spatial information of buildings (footprints), parcel boundaries and land use zones with attributes of building types. As one result, he achieves a quite accurate representation of the existing building stock. This model enables the investigation of future development and new scenarios based on building type and location. Through the integration of relevant building information and energy performance parameters in GIS, the representation of existing residential energy use patterns can be done across the community. Also future energy use patterns depending on construction techniques and different residential density patterns can be simulated with the presented concept.

A different approach to estimate the heating energy consumption is a method based on degree days. This method is “*widely used in energy consumption to plan and to estimate heating loads and storage requirements*”, as mentioned by SARAK (2002) and was applied to determine the natural gas consumption by residential heating in Turkey. For the calculation, SARAK (2002) uses the total yearly energy consumption $(\mathrm{Q_{h,yr}})_\mathrm{c}$ and the number (n) of residences (or apartments) of the city, the overall heat transfer coefficient (UA) for the building, the fuel heating value (H), the efficiency of the heating system (η_h) and the yearly heating degree days $(\mathrm{HDD_y})$.

$$(Q_{h,yr})_c = n\frac{UA}{H\eta_h}HDD_y$$

In the discussion chapter, SARAK (2002) points out to treat each city individually, because there are variations of the residence saturations for cities as well as of the number of the heating degree days. Finally, a relative distribution of the potential natural gas demand and areas with highest consumption densities were identified. Validations of the results were created with a comparison of the calculated energy consumption with the annual gas demand, obtained by the regional petroleum pipeline cooperation.

A bottom-up space heating demand model for the domestic stock of London is presented by MAVROGIANNI (2009). He started with data aggregation (building function, type and age) on building level and extracted it from digital maps. He aggregated the output data to the Middle Layer Super Output Area (MLSOA) level. This level of data aggregation was introduced by the Office for National Statistics (ONS) as Census output areas first and was chosen for the present study for several reasons.

First of all, this is the aggregation level on which London statistics are available, including gas and electricity consumption data. What is more, according to MAVROGIANNI (2009), that "*… the level of inaccuracy tends to increase when aggregated building stock characteristics are assigned to individual dwelling units*". The third reason for aggregating data to statistical units is the difficulty to consider individual occupancy and behaviours (MAVROGIANNI, 2009), which is also pointed out by SANTIN (2009). As complete data was only provided for limited areas, MAVROGIANNI (2009) took a subset for his case study.

The advanced part of MAVROGIANNI´s (2009) calculation algorithm (Building Research Establishment Domestic Energy Model – BREDEM) uses HDD from the London Site Specific Air Temperature (LSSAT) model. The heating degree day (HDD) value for any base temperature could be linked from the nearest LSSAT measurement site to each building polygon. The author also mentioned that other microclimatic factors like albedo, geometric characteristics or heat capacity of the surrounding area can influence the air temperature and trigger heat island effects. The BREDEM algorithm is also applied by RYLATT (2003). Finally, the model output was compared to annual household energy consumption statistics at MLSOA level, acquired from different statistical datasets (MAVROGIANNI, 2009).

The following chapter provides an overview about the required and optional data source to deal with in the context of GIS-based thermal energy demand mapping.

2.4.2. Minimum Requirements

The approach of DORFNER (2011) shows how to generate a grid-based map of the annual energy demand for room heating and hot water in a city. He points out the minimum input requirements, which are polygon layer of building outlines and the number of floors. Optional inputs are year of construction and measured energy consumption. The crucial information for the building database contains the total floor area (A_{bld}), which is predefined by the building polygon outlines ($Area = A_{polygon}$) and the number of floors (n_{floors}).

$$\mathrm{A_{bld}} = \mathrm{A_{polygon}} * \mathrm{n_{floors}}$$

This basic building information is used beside additional data from several authors (BIBERACHER, 2010; DORFNER, 2011; MAVROGIANNI, 2009; RYLATT, 2003; THUVANDER, 2009). Even some of them use data aggregation methods, depending on the level of data availability of regional statistics or energy consumption or demand information.

STRZALKA (2010) describes that the easiest way to estimate the heating energy demand is based on a typification of districts with a dependency on its size and the number of buildings in it, including their age. This method could be improved considering each building separately, using the value of the heated gross area. A combination of these methods is possible either.

2.4.3. Additional Data Sources

MAVROGIANNI (2009) distinguishes between residential and non-residential areas and classifies eight different building age types and 18 different build form categories. All data was derived from aerial photography interpretation and on-site surveys. Height information was gathered mainly from Light Detecting and Ranging (LiDAR) surveys. DORFNER (2011) suggested to estimate the number of floors ($n_{floors} = 0{,}32 * h_{bld}$), once the building height ($\mathrm{h_{bld}}$) is known. To focus on the heat demand of each building, the center point of each polygon has to be calculated and stored as an attribute.

For the specific heating demand (d_{th} in kWh/m²/a) of different building types DORFNER (2011) uses the classification from SCHLOMANN (2002). He differentiates between nine building types - residential small, residential big, office, trade small, trade big, industry small, industry big, other and zero. Moreover, the types "residential" and "office" are separated in different age types, which means that older buildings have a higher energy consumption index.

Then DORFNER (2011) multiplies the total floor area with the specific heat demand to obtain the total annual heat demand in kWh/a for each building.

$$D_{th} = A_{bld} * d_{th}$$

DORFNER (2011) summed up all values per cell of a 200*200m² raster, corresponding to the calculated center points. So he was able to visualize the accumulated estimated heating demand as raster cells in combination with polygons, showing the building outlines.

Due to a lack of statistical data and data availability in general, BIBERACHER (2010) developed reference buildings to show the individual heating and cooling demand for different building types (single-family home, apartment house, non-residential building, ….) in 2010. Criteria for the reference buildings are building type and use, quality of building envelope and location. The actual demand was assigned by spatial identification of the building stock and allocation of the particular buildings to the reference buildings. As the quality of the building envelope depends on the age of the building, the author uses five classes of building age for the residential buildings and no classification for non-residential buildings. To calculate the heat demand for buildings, also information about the location, which contains altitude and climate zone based on the energy pass (BIBERACHER, 2010), is necessary.

The Swedish author THUVANDER (2005) tried to find different data sources to visualize environmental data by mapping energy use on different levels. He focused on the city of Goteborg to establish an energy model based on GIS. His data source consists of real-estate and building data, which was obtained from the building register of the National Survey Sweden. Moreover, they used energy data from the energy supplier Goteborg Energi AB and the three real-estate managers in Goteborg, as well as energy statistics from Statistics Sweden.

The energy data provides information about the energy use for heating and hot water and the type of energy/energy carriers describe the heating system (gas, district heating and electricity). The data scale ranges from buildings to parts of the town. The building stock model maps the structural building information (year of construction, use of building, real-estate owner). To decrease data gaps and to receive a complete dataset, a ‘top-down’ approach is combined with a ‘bottom-up’ approach (i.e. statistical data with building data). The energy model combines energy statistics and age-use matrix for buildings with a spatial dimension and uses thematic layers describing population, road network, terrain and so forth. Climate information should be considered at this point as well (THUVANDER, 2005).

JONES (2001) made assumptions about the number of rooms, U-values, floor and roof based on age as, water heating and heating source, water tank volume (120l) and finally the heating system. Assumptions are considered to improve survey conditions but should be verified beforehand. In the end, this method refers to properties for 20 building types with five different age groups. Other models also use the building form or types of tenure, whereby the building form utilization has a lot of influence on the results of the estimated energy use.

GIS is likely used for urban planning processes and visualization, whereas most of them refer to 2-dimensional data entities like building footprints, roads or other urban areas. The above-mentioned methods deliver a rough estimation of energy demand in the specified areas. The approach with 3D building models, which is outlined in the following chapter, is even one step ahead.

2.4.4. 3D City Model

A recent example of calculating the heating energy demand of buildings, based on a 3D city model, is presented by EICKER (2010). It shows that a 3D city model, also with low geometrical detail, can be used to estimate the energy demand on urban scale with good results. The primary objective of the authors was the development of an energy management tool to predict and analyse the energy demand of urban quarters using the example of Scharnhauser Park, a modern residential area in the south of Stuttgart.

All tasks were managed with the least possible input parameters, as the level of detail of input parameters depends on data availability questionable on city scale. To generate a semantically enriched and topologically correct 3D model (blocked or detailed), encoded in CityGML (OGC, 2008), building footprint areas and the average building height were used. The latter was extracted from airborne laser scanning data. The building footprints and the building type information were derived from ALK-map (EICKER, 2010). How to extrude a topologically correct 3D city model is demonstrated by LEDOUX (2011).

In this case, it was very important to calculate the total area per building outer walls, walls between buildings, ground floor and roof. The measured heating energy consumption was gathered from a local energy supplier and stored in an access database. Heat transfer coefficients were taken from the thermal insulation specification, assigned for two building groups (row houses and multi-family houses). To map air temperature and global radiation, the authors used annual data from local weather stations (EICKER, 2010).

To manage all these different data sources, a 3D data management framework was developed to handle data input with different data formats, data manipulation and data output. The output file included all necessary building information and could be read by the building simulation model INSEL (www.insel.eu). The workflow to calculate the heating energy demand is presented in the following figure.

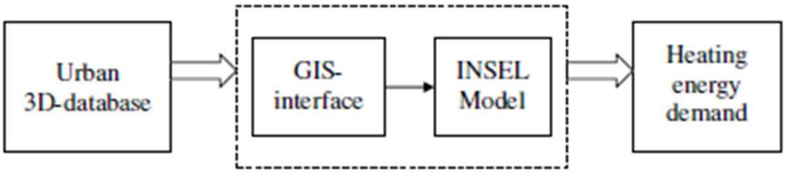


Figure 6: Workflow of Data Exchange (EICKER, 2010)

To calculate heating energy demand and to achieve good results, two methods have been tested. The first one considered only the transmission losses through the building envelope and the second computed the whole energy balance (transmission and ventilation losses), solar and internal gains. Assumptions like heating set-point (20°C), air change rate (0,5 l/h) or internal heat gains (5 W/m²) were made, depending on the method type (EICKER, 2010).

Discussing building rehabilitation, RAMOS (2004) points out that "*Increase in energy efficiency and reduction of greenhouse gas emissions of buildings can be achieved through improvements made in the existing stock of buildings.*" From this starting point, the authors designed a 3D GIS to evaluate the environmental properties of buildings and to detect improvement potentials. The system consists of entities that represent the geometry of buildings (geometry model) and their linked environmental information, distinguished as architectural model. The latter consist of information about buildings (age, type of structure, height or conditions) and their occupancy (dwelling, commercial, office, business, industrial ...), levels (stories), surfaces (walls, grounds, roofs) and surface elements. A defined distinction between external and shared walls is important for energetic issues.

In case of estimating thermal loads (*energy necessary for heating and cooling the building),* two methods are suggested by RAMOS (2004). The "monozonal approach" considers a building as a single thermally homogenous zone. The "multizonal approach" divides a building into zones or levels and allows estimating the distribution of the load within buildings.

2.4.5. The Usage of INSPIRE conformal Data Source

With the INSPIRE directive (2007/2/EG) of the European Parliament and the Council (from the 15th of Mai 2007) and its implementation in the federal "*Geodateninfrastrukturgesetz* -

GeoDIG[1], 2010)", the legal basis for the development of a national geodata infrastructure (GDI) was established. The main purpose of INSPIRE is the public deployment of existing national data without administrative restrictions. The content of INSPIRE consists of metadata, data specification, network services, data service sharing as well as monitoring and reporting.

In context of this master thesis it would be a benefit to retrieve building and energy information in an INSPIRE conformal data format (XML or GML) to establish a sustainable data base without interoperability and data integration problems. The two Austrian Geodata portals "INSPIRE Österreich" (www.inspire.gv.at/Geoportale/National.html) and "Geoland" (http://www.geoland.at) were evaluated to gather relevant data, but there were no data sources for buildings or energy-related topics available, although amongst others, buildings and energy resources are part of the INSPIRE feature catalog.

2.5. Conclusion

This chapter has dealt with different approaches to map the thermal energy demand via GIS-based methods, starting with surface models and their minimum requirements (building footprints and height to calculate the total floor area). Additional information contains building age, type and occupancy. These examples have shown that it is essential to distinguish between residential and non-residential areas, whereas residential areas could be subdivided into two or more classes (e.g. one-family house, two or more family house, block of flats, apartments, cottages ...). It was also pointed out that it is hardly possible to gather comprehensive information of the building stock of an entire city. Therefore, alternatives like reference buildings, data aggregation or subset data sets should be considered. In some cases assumptions can either be useful to optimize results.

Most of the cited models use bottom-up approaches and start with building footprints and then accumulate the necessary building or energy-related information. This seems to be a reasonable basis, but also publically available top-down data (e.g. statistical information, energy consumption, if possible energy measurements) for a specific level of aggregation have to be collected.

More accuracy provides the 3D city model approach. It was pointed out that it is possible to achieve good results with low detail building blocks (LoD1), although the level of detail has a lot of influence on the outcomes. A higher level (LoD2) requires the calculation of the total area

[1] *14. Bundesgesetz über eine umweltrelevante Geodateninfrastruktur des Bundes (Geodateninfrastrukturgesetz – GeoDIG), (NR: GP XXIV RV 400 AB 590 S. 53. BR: 8276 AB 8279 S. 781.)*

per building outer walls, walls between buildings, ground floor and roof. In case of the mentioned examples, this was not applied for entire cities, but only city districts.

Chapter 3 “*SOLUTION APPROACH*” will provide an appropriate way to combine those inputs and will present a feasible technique to model thermal energy demand mapping for city districts or entire cities.

3. SOLUTION APPROACH

The previous chapter presented various approaches to model the thermal energy demand of buildings in specified regions. This part of the thesis deals with the development of an own methodology for further investigations. An introduction into theoretical methodology and data acquisition process will be provided in this section.

3.1. Theoretical Methodology

3.1.1. Introduction

It was shown by ISAAC (2006) that the only reasonable way to gather information about household energy end-use is the accomplishment of detailed energy and temperature monitoring, occupant surveys and energy audits, which of course are very time-consuming and expensive. He describes the relationship between house, appliances and occupant behaviour as such a complex one that it is not possible to predict energy use accurately and that thermal models are no substitutes for monitored data (ISAAC, 2006).

- *No matter how bizarre the behaviour, somewhere, someone is doing it.*
- *There is no practical maximum to the number of appliances of a particular type in a house – somewhere, someone is collecting it.*
- *Any imaginable (or unimaginable) electrical appliance can be found in houses.*
- *There is no practical maximum or minimum energy consumption.*

This shall underline the fact that every approach to model the end-use load or the thermal energy demand of a specified entity will provide only a rough estimation, depending on data availability and accuracy, measures and assumptions as well as the spatial scale or the statistical unit within urban or rural regions.

3.1.2. Methods

Despite all difficulties, several techniques exist for modelling the energy consumption. *Figure 7* gives an overview of various techniques mentioned by SWAN and UGURSAL (2009), which are used for modelling the energy consumption for the residential sector. The authors basically distinguish between a ‘Top-Down’ and a ‘Bottom Up’ approach, whereas other sectors could be covered as well via data input modifications.

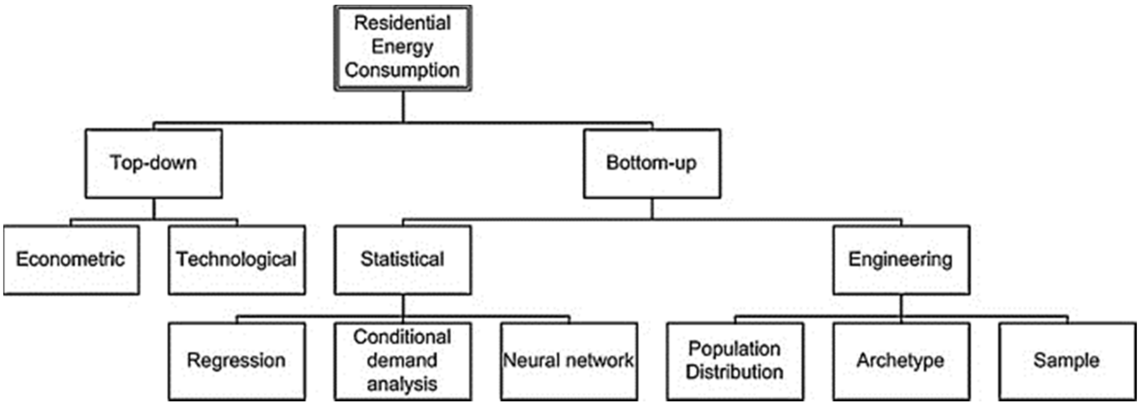


Figure 7: Top-Down and Bottom-Up Modelling Techniques for Estimating the Regional or National Energy Consumption (SWAN and UGURSAL, 2009)

Concerning the 'Bottom-Up' approach with its statistical and engineering method, each technique uses different levels of input information as well as different calculation techniques, which affect the results and the applicability.

The 'Top-Down' approach disregards the individual end-use and utilizes aggregated energy values to regress the energy consumption of the housing stock as a function of macroeconomic values like gross domestic product, inflation or employment rate (SWAN and UGURSAL, 2009). At this point it has to be mentioned that THUVANDER (2005) uses statistical data as 'Top-Down' information.

3.1.2.1. Building Model

Chapter 2.4 displayed that it is essential to establish a building data base first and then to model the thermal energy demand of buildings in an appropriate way. GIRARDIN (2012) points out three different methods, whereas two of them are similar to the suggestions of ISAAC (2006) regarding real time measurements and in situ identification of parameters. Concerning this thesis, the only practical approach uses the building geometry and thermodynamic parameters to predict the behaviour of a building.

The proposed methodology will not go into to detail of modelling the hourly building energy load behaviour, but the annual thermal energy demand in a specified region. Hence, it is necessary to collect data on the building level first, in order to develop a building data base. This building model should include geometrical properties (e.g. area, volume, height,…), geographical (climate, topography,…) and building properties (facilities, measures or other attributes). If all relations within the building model are mapped, energy-related values can be considered.

3.1.2.2. Archetype Method

Like WEBSTER (2009) mentioned, characterizing the energy use of a building includes quantifying the total annual energy consumption, building features (geometry, size,…) and mechanical systems (furnace, hot water) that impact the energy consumption and last but not least occupancy (cf. ISAAC, 2006). Due to a large amount of different building types within a city, it is necessary to classify buildings concerning these aspects. As it is not possible to cover all issues, a compromise has to be found.

Various approaches (BLESL, 2002; DORFNER, 2011; MAVROGIANNI, 2009; WEBSTER, 2009) developed a “Use-Age” matrix to distinguish reference buildings concerning age/renovation period and type or usage. Regarding the building construction period, assumptions can be made concerning heating system or insulation (u-values), occupancy can be assumed due to usage or type of building.

As the basic information concerning energy demand and building is available, data aggregation methods for analysis or visualization issues have to be considered.

3.1.2.3. Data Aggregation

Statistical data aggregation uses quantitative functions (i.e. sum, average, minimum or maximum) to combine or calculate different numeric values into one single result. Using GIS, the hyponym ‘aggregation’ summarizes quantitative methods to transfer data to a higher level of hierarchy, which is essential for using data on different information levels (BILL, 2010).

For example, someone aggregates population within different dwellings to residents of a statistical unit or district (see *Figure 8*). Aggregating polygons is equal to generalization issues and changes the shape of simple polygons. Their attributes could be summarized or calculated at the end of the process. Beside numerical values, data aggregation can be applied also to specific energy related indicators, which means that they are irrespective of the spatial scale or hierarchy level. For example, MAVROGIANNI (2009) aggregated building data to the Middle Layer Support Output Area (MLSOA), which is a statistical aggregation level.

The following figure shows different aggregation levels using the example of an urban study by GIRARDIN (2012).

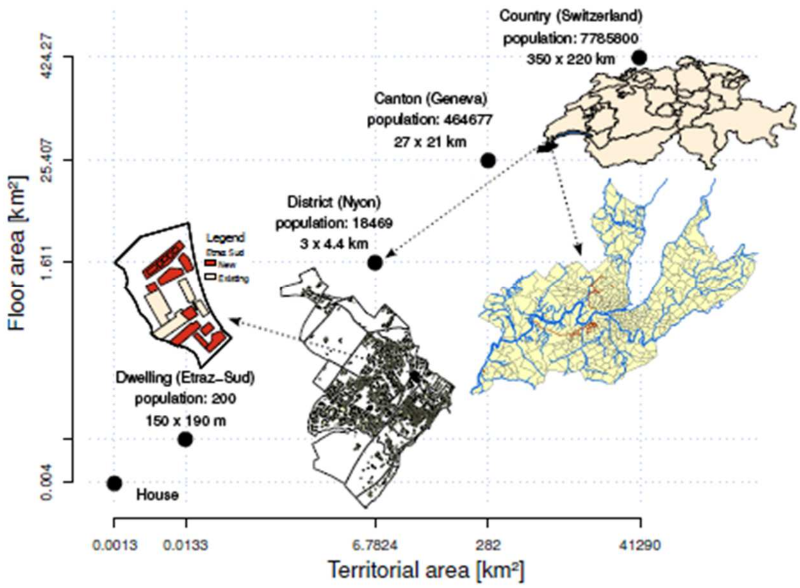


Figure 8: Log-log Plot of the Magnitude of the spatial Scale to deal with in urban Studies (GIRARDIN, 2012)

3.1.2.4. Heating and Cooling Degree Days (HDD, CDD)

Considering the thermal energy demand of buildings also implies the overall constitution of environmental and especially climatic impacts in the region of interest, depending on weather conditions and climatological seasons. This contains the temperature over the day and monthly or annual temperature, depending on time scale of investigation. The same applies to solar radiation or wind effects, which are also dependent on location, slope or aspect of relevant surfaces (i.e. roof, wall). Going into detail would also mean to look at microclimatic factors, such as heat island intensity, albedo, heat capacity and geometric characteristics of adjacent areas, which were pointed out by MAVROGIANNI (2009).

Hence, to avoid complex formulas and not to raise problems due to data availability, climatologists use degree days to estimate the energy demand quite accurately. They assume that room heating is necessary on any day with an average outdoor temperature less than a specified value and vice versa. Regarding to PREK et al (2010), this method captures extremity and duration of outdoor temperatures, as degree days are essentially the summation of temperature differences over a time period (PREK et al, 2010). This complies with the standard or average method for heating degree days (HDD), also mentioned by BROWN et al (2007), as shown in the following equation.

$$HDD = T_b - \left(\frac{(T_{max} - T_{min})}{2}\right)$$

Also MATZARAKIS (2004) applies this formula and further points out of HDD as an excellent tool to quantify the energy demand in any region, nevertheless to consider that the basic air temperature for the determination of HDD depends on the building specification. Likewise, KRESE (2011) recommends to determine the base temperature for each building, as beside building characteristics, the base temperature also depends on internal and external heat gains (i.e. people, appliances, fenestration, infiltration, …) and on the set indoor temperature.

The international definition of HDD and CDD uses the balance point temperature of 65°Fahrenheit or 18.3°C, which means that a daily average temperature higher than 18.3°C defines CDD and HHD if the temperature is lower than this value. In alpine regions and especially in Austria, this balance point value is not usable. For example, the daily average temperature is lower than 18.3°C for more than 300 days a year (Graz, Airport Thalerhof from 1971-2000). Therefore, the value of 12°C mentioned by the ÖNORM 8135 in Austria is used to define HDD as a difference between constant room temperature (20°C) and daily average outdoor temperature below 12°C, which results in the sum of HDD´s (PRETTENTHALER, 2007).

$$HGT(T_1, T_2) = \sum_{t=T_1}^{T_2} (20 - \theta t)$$

with $\theta t \leq 12$

Concerning CDD, simple methods are also preferred regarding KRESE et al (2011), because they are more appropriate than time-consuming and complex computer simulations. The authors define CDD as the sum of a positive difference between outdoor air temperature θ_o and base temperature θ_b over a certain time period. The base temperature refers to the maximum outdoor temperature at which the thermal comfort inside the building keeps preserved without cooling (KRESE et al, 2011).

$$CDD = \sum (\theta_o - \theta_b)$$

BROWN et al (2007) define CDD as:

$$CDD = \left(\frac{(T_{max} - T_{min})}{2}\right) - T_b$$

In Austria there exists no definition for CDD, as the energy consumption for cooling is more heterogeneous than for heating. Especially office buildings have a high energy demand for cooling during the summer period compared with no cooling demand for the most of the residential buildings (PRETTEHTHALER, 2007). The following table, shown by PRETTENTHALER (2007), demonstrates the variety of CDD (*Graz, Airport Thalerhof* from 1971-2000), depending on the base temperature as well as on the climatic characteristic of the time period. In this case, the amount of CDD diverges from 4.9 (cool summer 1990) to 497.6 (hot summer 2003). Finally, PRETTENTHALER (2007) prefers 18.3°C as base temperature, especially as the variability of CDD is described best with this value.

Table 3: Interannual Variability of Base Temperatures from 18.3, 20 und 22°C, at Graz-Thalerhof from 1971-2000 (PRETTENTHALER, 2007)

Periode	Kühlgradtage			Anzahl der Tage		
	$CDD_{18,3}$	CDD_{20}	CDD_{22}	>18,3℃	>20℃	>22℃
1971-2000	**142**	**61**	**16**	**61**	**34**	**13**
Standardabweichung	61	39	18	16	13	9
Variationskoeffizient	0,43	0,65	1,07	0,26	0,38	0,74
2003 – heißer Sommer	497,6	315,2	151,7	113	99	64
in % zu 71/00	*350%*	*516%*	*921%*	*185%*	*294%*	*509%*
1990 – kühler Sommer	105,2	34,9	4,9	51	30	5
in % zu 71/00	*74%*	*57%*	*30%*	*84%*	*89%*	*40%*

Additional and more complex methods are described by BROWN (2007), namely the modified Growing Degree-Days (GDD) method, the Sine Curve method or the Hourly Average Integration.

PREK et al (2010) show how degree days can be used to define the total energy demand (Ed) of buildings for an individual number of days. The authors multiplied the number of days in a given period (N_d) with the base energy demand at temperature (Tb) plus degree days multiplied with thermal loss and gain (α, β). They obtained best results for heating with constant internal temperature, thermal losses/gains and building properties.

$$\mathrm{Ed} = \mathrm{N_d} * \mathrm{Ed_{Tb}} + \alpha * \mathrm{HDD} + \beta * \mathrm{CDD}$$

α … total specific thermal loss
β … total specific thermal gain

3.2. Thermal Demand

The following section provides a description of the applied calculation method. The final result shall cover the annual usable energy demand for heating and cooling within a specified region.

At the beginning, the most important characteristics and the significance of the applied method will be clarified.

3.2.1. Characterization of the Thermal Demand

Energy demand is a calculated or measured value, both on the level of final energy and on the level of usable energy. The **final energy demand** ("*Endenergiebedarf*") is the real amount of consumed energy calculated at the system boundary of the considered building. It is the amount of energy that must run through the heating system and all other technical energy systems to satisfy heating and hot-water demand, comfort requirements for ventilation, cooling and lighting (OIB, 2011b).

The modeling of the final energy demand implies limiting conditions, like indoor heating source and system, occupancy or personal behavior. The **heating energy demand** ("*Heizenergiebedarf*") on the level of final energy includes also thermal loss through heating systems and energy for hot-water preparation, therefore all existing parts of the heating system have to be calculated (cf. ÖNORM H 5056: ASI, 2007). Thus, this method is not usable, also due to the non-availability of real consumption data.

On the level of usable energy, the **heating demand** ("*Heizwärmebedarf*", HWB) describes the amount of energy necessary to preserve the desired room temperature for a conditioned building (ASI, 2010). The same applies to **cooling demand** ("*Kühlbedarf*", KB). This approach will focus on the heating and cooling demand on the level of usable energy. Hence, the applied calculation method will focus on the buildings energy balance, including all gains and losses, like visualized in *Figure 9*.

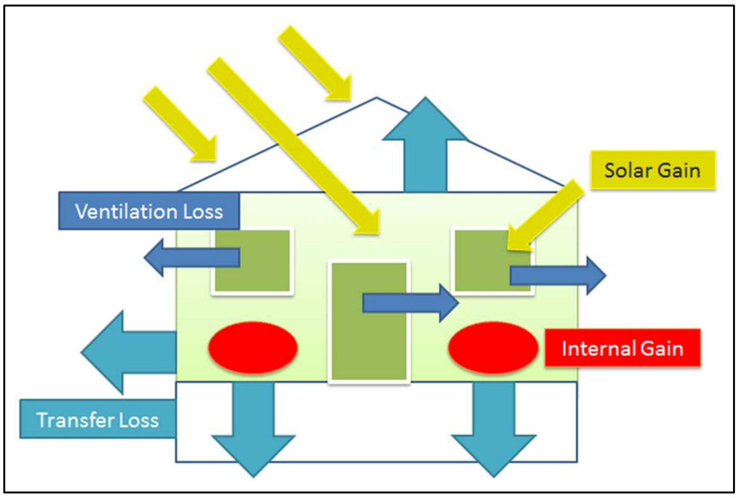


Figure 9: Schematic Illustration of the Energy Balance of Buildings

The basis for the demand model process is used from ÖNORM B 8110-6 (ASI, 2010), which delivers an appropriate method to calculate the monthly thermal demand for a building. This includes the demand for heating and cooling with a distinction of residential and non-residential buildings. The applied method is sparsely modified to deliver not the monthly balance, but the annual sum of all thermal gains and losses (cf. FREY et al, 1994).

3.2.2. Heating Demand ($\boldsymbol{Q_h}$), Cooling Demand ($\boldsymbol{Q_c}$)

The demand for space heating or cooling within a building is described as the balance between thermal losses (ventilation and transmission) and thermal gains (internal and external) and conforms to the amount of energy, which is necessary to maintain the basic internal temperature during the heating or cooling period. As a reference, an indoor temperature of 20°Celsius will be assumed for the heating demand calculation. The maximum indoor temperature in case of cooling is 26°C (cf. ASI, 2010). The annual heating ($\mathrm{Q_h}$) and cooling demand ($\mathrm{Q_c}$) is described with following equations:

$$Q_h = (Q_T + Q_V) - \eta_h * (Q_S + Q_I)$$

$$Q_c = (Q_T + Q_V) + (Q_S + Q_I)$$

$Q_{h,c}$……. *Heating/Cooling Demand (kWh/a)*
Q_T……… *Transmission Heat Loss (kWh/a)*
Q_V……… *Ventilation Heat Loss (kWh/a)*
η ……… *Utilization Factor (Heat Gain)*
Q_S……… *Solar Gains (kWh/a)*
Q_I……… *Internal Gains (kWh/a)*

3.2.3. Thermal Losses

According to ÖNORM B 8110-6 (ASI, 2010), the overall thermal losses (Q_l) have to be calculated as sum of the transfer (Q_T) and ventilation (Q_V) losses.

$$Q_l = Q_T + Q_V$$

3.2.3.1. Transmission Heat Loss ($\boldsymbol{Q_T}$)

The major heat loss aspect concerns transmission. Interacting factors are the surface area of the building envelope (A_i), the difference between indoor and outdoor temperature, defined as HDD (CDD) and the heat transfer coefficient of the building elements. Due to the difficulty of gathering information on transfer coefficients for all different buildings, default U-values (measure of heat transfer per building element) for residential buildings exist, even different standards for each federal state (OIB, 2011b).

At first, the overall heat transfer coefficient L_T (W/K) has to be calculated. This value consists of the coefficient sum of all building elements, (external/internal walls, rooftop area and ceiling area) and considers all surface areas of the building envelope. Default or standard U-values (cf. *A*) have to be used according to guideline 6 (OIB, 2011b). Beside the building elements, also linear and point thermal bridges have to be considered, but won´t be applied to this approach. The entire formula for the simplified calculation of L_T (W/K) looks like follows (cf. ASI, 2010).

$$L_T = \sum_i f_{i,h,c} * A_i * U_i + (L_\Psi + L_x)$$

$f_{i,h,c}$ …… *Temperature Correction Factor*
U_i ……… *Heat Transfer Coefficient (W/m²K)*
A_i ……… *Surface Area (Building Envelope) m²*
L_Ψ ……… *Heat Transfer Coefficient for linear Thermal Bridges (W/K)*
L_x ……… *Heat Transfer Coefficient for point Thermal Bridges (W/K)*

The only distinction between heating and cooling demand refers to the temperature correction factor ($f_{i,h,c}$), which varies with regards to following building elements.

Table 4: Default temperature correction factors

Building elements and temperature correction factor*	f(i,h)	f(i,c)
Ceiling to unconditioned basement	0.9	0
Ceiling to unconditioned attic	0.7	0.7
Outdoor wall without window area	1	1
(*ASI, 2010)		

The result of the heat transfer coefficient L_T is specified in W/K. To obtain the annual amount of transmission heat loss in kWh/a, it is necessary to multiply the value with the HDD and a conversion factor of 0.024 (for 24 hours per day).

$$Q_{T,h} = L_{T,h} * HDD * 0.024$$

$$Q_{T,c} = L_{T,c} * CDD * 0.024$$

3.2.3.2. Ventilation Heat Loss ($\boldsymbol{Q_V}$)

The second part of thermal losses touches the ventilation heat loss (Q_V), which depends on occupancy (air exchange usage) and the tightness of a building. Since there is no information available about air condition or other technical cooling systems, the applied method uses standardized air exchange rates regarding to ÖNORM B 8110-5 (cf. ASI, 2011b). The annual calculation includes both residential and non-residential buildings.

L_V for all buildings:

$$L_{V,h,c} = c_{p,L} * \rho_L * n_L * V_V$$

$L_{V,h,c}$.... Heat Transfer Coefficient by Ventilation (W/K)
$c_{p,L}$…... Heat Capacity of Air (1.006kJ/kgK)
ρ_L……. Density of Air (12kg/m³)
→ Volume sourced heat capacity of air: $c_{p,L} * \rho_L = 0.34Wh/(m^3K)$
n_L……. Effective Air Exchange Rate in 1h
→ Minimum air exchange rate (n_L=0.4 l/h)
V_V……. Energy Related Air Volume (m³)

Standardized values are used for the **air exchange rate** (n_L) and the **heat capacity of air** ($c_{p,L} * \rho_L = 0.34Wh/m^3K$). With the input of the heat transfer coefficient by ventilation, it is possible to calculate the annual thermal loss by ventilation for residential and non-residential building.

$$Q_{V,h} = L_{V,h} * HDD * 0.024$$

$$Q_{V,c} = L_{V,c} * CDD * 0.024$$

3.2.4. Thermal Gains

According to ÖNORM B 8110-6 (ASI, 2010), the overall thermal gains (Q_g) have to be calculated as sum of the monthly thermal (Q_S) and internal (Q_I) gains.

$$Q_g = Q_S + Q_I$$

3.2.4.1. Internal Heat Gain ($\boldsymbol{Q_I}$)

According to ÖNORM B 8110-6, internal heat gains emerge through electrical appliances, lightning and body heat. Due to missing information concerning electrical appliances and lightning, the simplified method with default heat gain values will be applied for all building types (cf. ASI, 2010).

For residential buildings a heat gain value (q_i) of 3.75 W/m² is provided. Non-residential buildings use further default values (cf. ASI, 2010, *A*). The overall internal gains for heating and cooling are represented with following equations. The usage of heating and cooling days differs from previous calculations.

$$Q_{I,h} = 0.024 * q_i * A_R * HD$$

$$Q_{I,c} = 0.024 * q_i * A_R * CD$$

$Q_{I,h,c}$…Internal Heat Gain
q_i…….Internal Heat Gain per m² A_R
- *(for residential buildings q_i = 3.75W/m²)*

A_R……Energy Reference Area (m²)
HD…...Heating Days
CD……Cooling Days

3.2.4.2. Solar Gains ($\boldsymbol{Q_S}$)

The calculation of the overall thermal gains includes the total annual solar irradiation per m² (I_j) with a given orientation (j), the solar active collecting area (A_g) and the shading reduction factor (F_s). ÖNORM B 8110-5 (ASI, 2011b) provides the monthly solar irradiation per orientation as well as transposition factors for inclination of building elements and solar angle. For all transparent building elements, an azimuth of 90° is assumed. As the overall calculation is based on the irradiation per month, a distinction has to be made concerning heating and cooling season.

$$Q_S = \sum_j I_j * (\sum A_g * g_w * F_s)_j$$

I_j…... Total Solar Irradiance per m² (kWh/m) with an Orientation j
A_g…. Solar Effective Area (m²)
g_w…. Solar effective g-value
F_s …. Shading Reduction Factor

Solar Effective Collecting Area (A_g)

All glazed or transparent elements (e.g. windows) of the building envelope in m² belong to the solar effective collecting area. The default glass ratio (f_g) per the window area (A_W) is set to 0.7 (cf. ASI, 2010).

$$A_g = f_g * A_W$$

Solar Effective g-value (g_w)

The default g-values (cf. ÖNORM B 8110-6) have to be corrected concerning non-perpendicular radiation (0.9) and dirt (0.98).

$$g_w = 0.9 * 0.98 * g$$

Shading Reduction Factor (F_s)

The simplified method assumes a shading reduction factor $F_s = 0.85$ for all single family, double family and row houses. For all other buildings a shading reduction factor $F_s = 0.75$ has to be used in case of heating. For cooling, a shading reduction factor $F_s = 1.0$ shall be used for all building categories (cf. ASI, 2010).

3.2.5. Synopsis

To achieve all requirements within a single environment, the main benefit of GIS emerges. It allows dealing with all mentioned methods, starting with the data input and management for the building database. *Figure 10* gives an overview about the planned workflow in order to model the thermal energy demand for a specified city. After data aggregation and energy demand modeling, it depends on the chosen case studies (district, city quarter…) how the single processes should be configured.

For best results it is important to consider the individual building for the energy demand calculation, including building properties and building geometry. Moreover, environmental aspects should be part of the methodology as especially the climate situation is an assessable and very important variable.

An additional input was provided by GIRARDIN (2012), who mentioned to deliver per capita indicators on maps, which can be achieved through the relationship between population register and geographic area or building. This aspect could be also of interest concerning the result evaluation process.

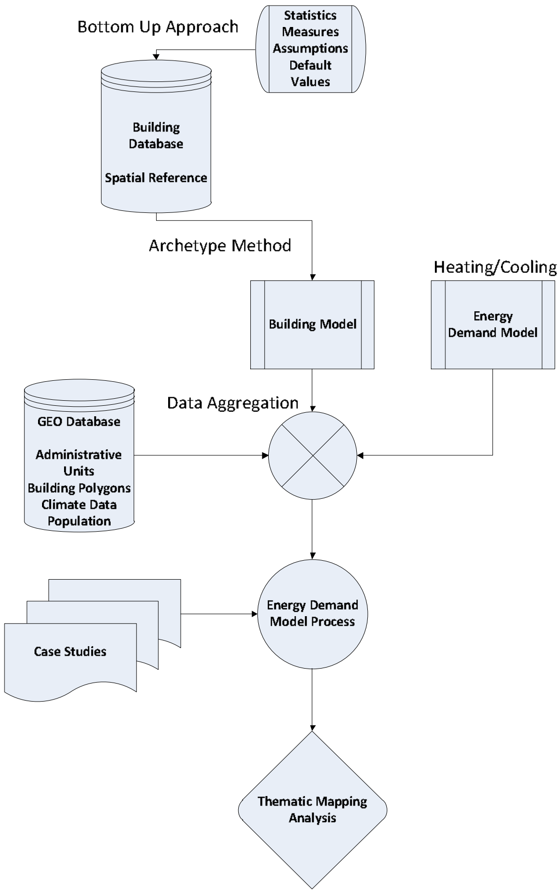


Figure 10: Suggested Workflow for the Demand Model Process

3.3. Data Acquisition Process

This section contains a short description of the needed data sources and their acquisition process. As the most important information concerns buildings and their properties, there is a special focus on this issue.

3.3.1. Building Attributes

At this point it should be clear that it is essential to know at least some minimum requirements of a building, which can be the footprint and the number of floors. The more information can be gathered for one building, the more modelling potentials and increasing accuracy is possible, of course depending on the used calculation method. Hence, it is more than useful to establish a building data base gaining all available information to work with flexibility and sustainability.

Looking for appropriate data sources, it becomes apparent that the Austrian GWR (‘*Gebäude und Wohnungsregister*’), based on the GWR – law[2] with its latest modifications[3], could deliver all really important information’s about building or dwelling feature, utilization unit or energy

[2] Bundesgesetz über das Gebäude- und Wohnungsregister (GWR-Gesetz) StF: BGBl. I Nr. 9/2004 (NR: GP XXII IA 309/A AB 383 S. 46. BR: 6960 AB 6962 S. 705.)

[3] BGBl. I Nr. 125/2009 (NR: GP XXIV RV 320 AB 419 S. 46. BR: 8199 AB 8216 S. 779.) [CELEX-Nr.: 32002L0091] BGBl. I Nr. 1/2013 (NR: GP XXIV RV 1984 AB 2036 S. 184. BR: AB 8849 S. 816.)

pass (cf. BLESL, 2002 '*Gebäudedatenmethode*'). Also THUVANDER (2005) refers to the building register of the national survey Sweden. The energy pass data base was first integrated in the year 2010, thus it has to be assumed that there exists no comprehensive data available yet. Beyond that, the GWR refers to the address register (AR) of buildings and parcels which are referenced to administrative units within Austria.

Based on the legal basis of the GWR-law, the establishment of the 'Address-GWR Online', a tool to gather all required data, was done by Statistic Austria with the kick-off date in November 2004 (since 2010 AGWR II). The responsibility to supply building information with this tool is obliged to the communities, as well as their possibility to use data within their regions and for own purposes. For privacy reasons, no public access to individual data is given. Analyses from the register are possible, taking into account the statistical obligation of confidentiality (STATISTIK AUSTRIA, 2013b). For data acquisition purposes this means that data availability depends on the progress of data delivery by community and on the cooperativeness of a community, too.

3.3.2. Population

Several per capita indicators, like mentioned in the section "*Literature Overview*", can both help to define the specific building energy loads and to evaluate the final results. This was pointed out by GIRARDIN (2012), in particular to deliver the relationship between inhabitants and geographic area or buildings.

In Austria, the register-based census is taken directly from already existing administrative registers since 2006, which includes mainly data that has also been collected for the census in 2001. As a result of the population census, applied by Statistik Austria, a numerical picture of the structure of the population is presented in Austria. These statistics are available also for cities which can use census results as a basis for administration issues, economic decisions or research projects (STATISTIK AUSTRIA, 2013c). The population census information is also available as 125m raster, which accords to the desired output format of the energy demand maps.

3.3.3. Other Data Sources

Using GIS of course requires some basic datasets like administrative borders or statistical units. Depending on the aggregation level this includes communities, districts or judicial districts like "*Zählsprengel*". Besides building polygons and population data, also climatic information shall be available. The latter shall at least contain information about degree days and solar radiation, derived from average temperatures per month and year.

4. PROJECT DESCRIPTION

The main chapter starts with a description of the pilot region and the data validation process. Energy-related aspects will be dealt with subsequent to a depiction of the building modeling process.

4.1. Pilot City and Data Source

Initially, the idea of this thesis was to compare the annual heating and cooling demand of two cities, in order to evaluate the results and the chosen method. Due to the unavailability of data from the Austrian building register, the comparison of two districts in the city of Graz has been selected for subsequent investigations. The applied method is applicable for other Austrian cities too and will be presented using the example of two districts ("*Inner City*" and "*Liebenau*"), in order to compare areas with different building structure and population density.

The statistic department of Graz delivered data out of the building register, more precisely the actual progress of the recorded building (status: 26.4.2013) stock of Graz within the AGWR. The data set includes properties like coordinates, construction period, building type, number of storeys and the build-up gross area. The Styrian Government, or more specifically the Department of Statistics and Geo-information, provided information regarding the population census, degree days and solar radiation in addition to basic geographic data like administrative borders and judicial districts. Furthermore, building polygons including building height, measured with Airborne Laser Scanning (ALS), are available.

Concerning the establishment of the building data model, it was decided to combine point properties from the building register with building polygons, in order to create a sustainable building data base (including geometric features), which can be analyzed and extended easily (e.g. development of a 3D model, spatial analysis,…). The next section will provide an overview about data integration and the validation process.

4.2. Data Validation Process

As the provided data has to be validated first in order to avoid data inconsistency and data errors, we need the building model process, which is introduced in this chapter. At the beginning, data integration into a common geographic reference system is essential. Additionally, the method of merging building point information with building polygons as well as the validation process will be explained.

4.2.1. Geographic Reference System

The geographic reference system, used with GWR, refers to a Gauß-Krüger projection with the meridian 34 (MGI_Austria_GK_M34) for Graz, using the Bessel ellipsoid (STATISTIK AUSTRIA, 2010). All data sources delivered by the Styrian Government (www.gis.steiermark.at, 2013) refer to UTM Zone 33 North, using the ellipsoid WGS 84 as a reference system (WGS_1984_UTM_Zone_33N).

Thus, the point information from the building register was transformed to the UTM Zone 33 North (transformation parameter: MGI_To_WGS_84_8, *Figure **11***). The result was verified with the open street map (OSM) layer and the building polygons (see example *Figure 12*).

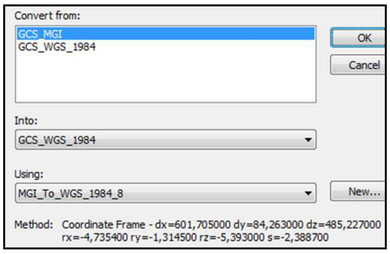


Figure 11: Transformation Settings

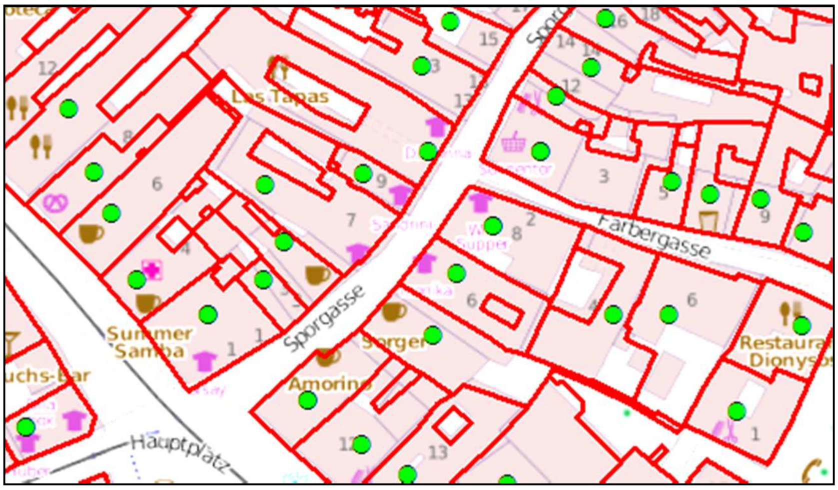


Figure 12: Verification of the Building Point (green) Transformation, with Building Polygons (red border) and OSM layer (source: City of Graz, GIS Styria, OSM; 2013)

4.2.2. Data Validation

4.2.2.1. Location Errors

To discover data errors, building points and polygons have been displayed together with an Open Street Map (OSM) layer in the area of interest. A first look at the building point properties showed that there are some problems concerning data consistency, integrity and positioning accuracy. For example, *Figure 13* (picture on the left) shows missing points at the right site, whereas these points are underlying the green points below (same coordinates). The same is valid for *Figure 13* (picture on the right), underlying 10 points of the neighboring polygons. These errors can be corrected with the assumption of the real location in combination with the building height and polygon shape area, as the number of storeys and the build-up gross area of the buildings are known.

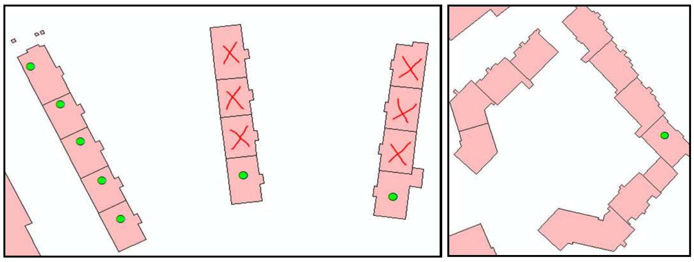


Figure 13: Building Point (green) Data Error compared with Building Polygons - wrong Positioning (source: City of Graz, GIS Styria, 2013)

Other problems occur due to missing points, wrong positioning of points (see *Figure 14*) or missing polygons. Some of the points without polygons can be allocated to the proper polygon, some of them cannot. If only the polygon (area, height) is available, the construction period and the building type have to be assumed or verified with other sources.

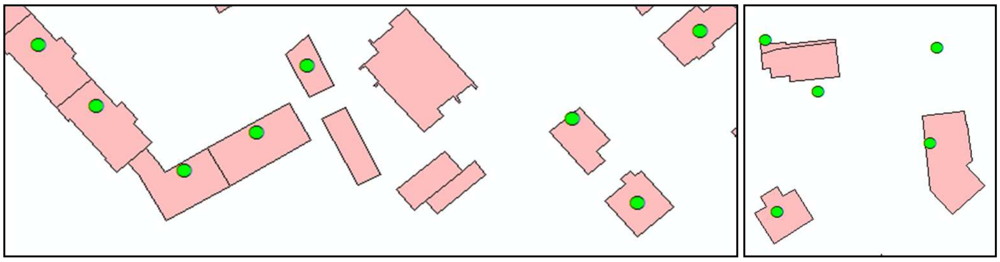


Figure 14: Building point (green) Data Error - missing Point (left) and wrong Positioning (right) (source: City of Graz, GIS Styria, 2013)

4.2.2.2. Content-related Errors

Especially data out of the building register has to be validated in terms of consistency. As indicated before, coordinate errors could complicate the development of the building model. In addition, several content-related errors have to be cleaned up. This affects in particular the building type and the construction period, which can be verified by the author, either through local knowledge or assumptions due to adjacent buildings.

4.2.3. Concept

As mentioned before, the building points out of the Austrian building and dwelling register, building polygons and building height serve as the basis for the building model. Since the spatial distribution of buildings is defined by coordinates too, the main benefit and reason to use polygons is the possibility to calculate geometric building features. Especially the volume area ratio or the specific length of a building are very important parameters (cf. *Chapter 4.4.1.4*). Hence, it is necessary to develop a process which leads to a maximum of usable building polygons. So, both building polygons and building points have to be cleaned up via defined conditions and then merged together to obtain a maximum of appropriate polygons. *Figure 15* presents this workflow in detail with all defined conditions.

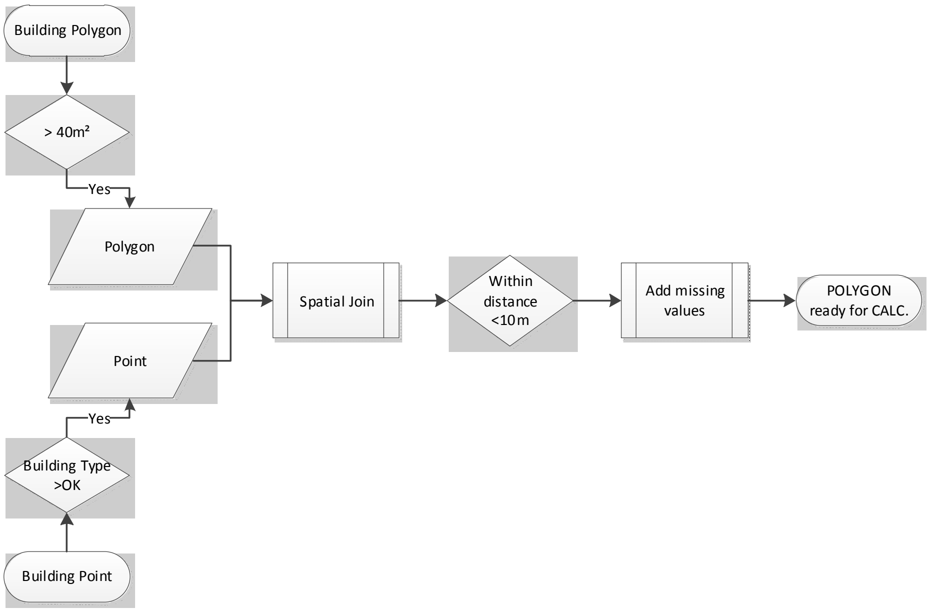


Figure 15: Flowchart of the Building Model Process

Conditions for building points:

1) Building Type [*Langtext_G*] **NOT IN** (*'Kirchen, sonstige Sakralbauten', 'Pseudobaulichkeit', 'freistehende Privatgarage', 'landwirtschaftliches Nutzgebäude', 'sonstiges Bauwerk'*)
2) Building Type [*Langtext_G*] **IN** (*'Wohngebäude für Gemeinschaften', 'Gebäude mit einer Wohnung' ,'Gebäude mit 2 oder mehr Wohnungen', 'Bürogebäude', 'Gebäude des Verkehrs- und Nachrichtenwesens', 'Gebäude für Kultur- und Freizeitzwecke sowie das Bildungs- und Gesundheitswesen', 'Groß- und Einzelhandelsgebäude' 'Hotels und ähnliche Gebäude' ,'Industrie- und Lagergebäude'*)
3) **Build-over area** of a building has to be **at least 40m²**.

Conditions for building polygons:

1) All polygons with an area less than 40m² are excluded from the building model process. These buildings are not relevant for thermal energy demand issues (e.g. garage, garden shed …).
2) The minimum building height contains 3m.

Conditions for point-polygon spatial join:

1) The point-polygon join by location shall include only building points that intersect with buildings or are within a distance of a building polygon of less than 10m.
2) Excluded polygons will be verified and if applicable added manually.
3) Plausibility check for all polygons (see *Figure 16*) will be done.

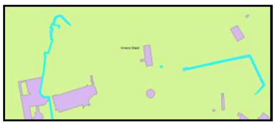


Figure 16: Plausibility check for Polygons

4.3. Case Studies

According to *Chapter 1 "Introduction"*, two districts of the pilot city will be compared and some basic facts shall underline the differences between the chosen districts.

4.3.1. Graz - Inner City

The 1st District or the "*Inner City*" of Graz conforms to the historical city centre of the Styrian capital and includes "*Schloßberg*" and "*Stadtpark*". The area is about 1.16 km² with 4155 inhabitants (31.12.2011) and a population density of 3.581 inhabitants per km² (MAGISTRAT GRAZ, 2012). This compact district is characterized by retail industry and services and serves as the hub for the urban public traffic, while most of the district is a pedestrian zone. Based in this district are the municipality of Graz, shopping centres, markets, museums and galleries, restaurants, pubs and bars. From initially 782 polygons, 621 are validated concerning size and location, occupancy and building age. The minor of them are residential buildings (288), whereas it should be clear that the building type is determined by the buildings' main occupancy.

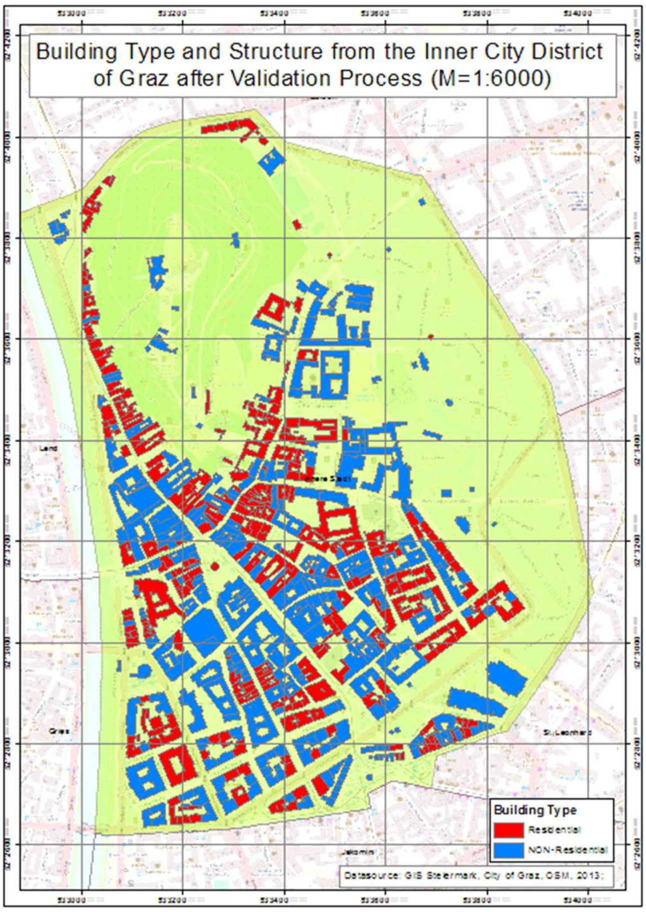


Figure 17: Area of Interest, Graz "Inner City"

(source: City of Graz, GIS Styria, 2013)

4.3.2. Graz - Liebenau

The 7th District of Graz, "*Liebenau"*, is completely different regarding building structure and population density. The area of this district is about 7.9 km² with a population of 14.116 (population density = 1787 per km², MAGISTRAT GRAZ, 2012). In *Liebenau* old crafts and agricultural plants are located besides industrial and business parks ("*Murpark"*).

The major part belongs to residential areas, whereas single family houses are frequent, especially in the south-west of *Liebenau*. In the south, a huge industrial base (Magna Steyr) is located on the area of the former "*Puch-Werke*". The output of the validation process (3412 polygons of 4376) delivers 3113 residential and 299 non-residential building polygons for further analysis.

Figure 18: Area of Interest, Graz "Liebenau"
(source: City of Graz, GIS Styria, 2013)

4.4. Demand Model

Subsequently, energy-related issues like building parameters or boundary conditions will be considered. This includes geometrical building features, building type and occupancy and last but not least climatic aspects.

4.4.1. Geometrical Features

Energy demand or consumption strongly depends on internal building properties or geometrical features, occupancy and environmental impacts. Hence, this fact requires a description of geometrical building features as well as relevant local climatic conditions first, in order to understand their relations and their effects on thermal energy demand.

4.4.1.1. Conditioned Gross/Net Floor Space

According to the ÖNORM H 5055 (ASI, 2008a), the calculation of the energy performance requires the specific heating demand as energy per gross floor space (GFS). The GFS is determined by the outer building envelope, with a wall thickness of 0.4m (cf. ÖNORM B 1800: ASI, 2013a) and contains the area of all floor levels. However, ÖNORM B 8110-6 (ASI, 2011b) refers to the net conditioned floor space as energy reference area, which can be converted as follows:

$$A_R = A_f * 0.8$$

A_R …... Energy Reference Area (m²)

A_f…… Conditioned Gross Floor Space (m²), polygon area

4.4.1.2. Conditioned Gross/Net Volume

According to ÖNORM B 1800 (ASI, 2013a), the conditioned gross volume is the sum of all conditioned room volumes, enclosed by the building. It is necessary to determine the net conditioned volume to calculate the ventilation loss, whereas a fixed room height of 2.6m is assumed.

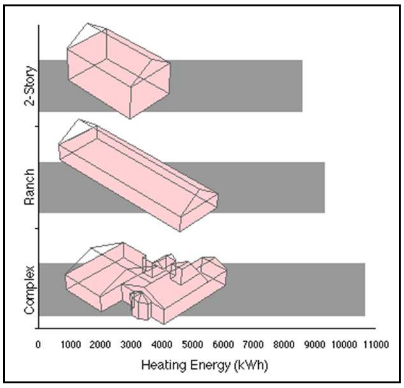
$$V_V = A_R * 2.6$$

V_V ……Energy Reference (Air-)Volume (m³)

A_R …… Energy Reference Area (m²)

4.4.1.3. Building Envelope

An essential aspect determining gains or losses of a building is the ratio between the outer surface and the volume of a building. The bigger the outer surface, the more transfer gains/losses can be expected, of course depending on the materials of construction. Hence, the form of a building determines the surface area which has an effect on the consumption of energy, both heating and cooling. The following example shows this effect, as all buildings have the **same** conditioned floor areas and insulation values, but different energy demand values (kWh). The statistical results were calculated for 4500 heating degree days (OIKOS, 2013).



Components	2-story	Ranch	Complex
Ceiling	1000	2000	2053
Wall	2210	1680	1941
Floor	1000	2000	2000
Volume	17000	16000	17250
Surface Area	4210	5680	5994
Heating Energy	8580 (kWh)	9300 (kWh)	10640 (kWh)
Heating Cost			
$0.05/kWh	429	465	532
$0.09/kWh	772	837	958
$0.13/kWh	1115	1209	1383

Figure 19: Effects on Heating Energy Demand due to different Surfaces of Buildings with same Conditioned Floor Space (OIKOS, 2013)

To calculate the outer surface (*A*) or envelope of a building, ArcGIS offers the "*polygon to line*" function to consider each neighborhood, resulting as a polyline feature. It contains the *left_fid*, which denotes if it is a boundary to another polygon or not (-1 indicates if it is an outer line) and the *right_fid*, which is the ID of the building shape (see *Figure 20*).

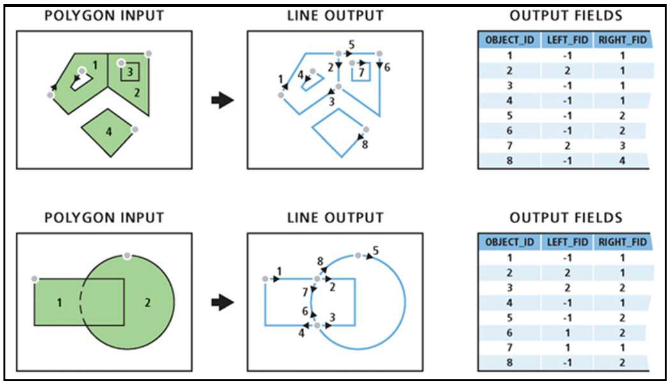


Figure 20: Method of the "Polygon to Line" Function (ARCGIS, 2013)

In a first step, all polylines with an attribute *left_fid* = -1 have to be used for the calculation of the building envelope. The perimeter values (outer surface line) have to be grouped by the *right_fid* (Polygon ID) and then summarized in order to join it with the initial polygon shapes (*object_id*).

Then, the total outline length per polygon can be multiplied with the building height. The gross floor area (as roof area) has to be added further, as no roof types are available.

4.4.1.4. Characteristic Length

An indicator of the building form is, according to the ÖNORM B 8110-6 (ASI, 2010), the compactness of a building, expressed by the characteristic length (l_c). It is calculated as the ratio between the volume (*V*) and envelope (*A*) of the building. The latter consist of all emitting building elements.

$$l_c = \frac{V}{A}$$

V…… Energy Reference (Air-)Volume (m³)
A…… Area (m²) of Building Envelope

Finally, all relevant geometrical building properties (gross/net volume and area, outer surface area and characteristic length) can be identified. Within this approach, further calculations are based on building LOD1 (cf. EICKER et al, 2010).

4.4.1.5. Area of Surface (transparent and opaque)

Of special interest concerning solar gains are all transparent building elements. This approach assumes that every vertical wall, adjacent to outdoor air, has a window fraction of 20% (default value, cf. ASI, 2011a), which refers to the solar effective collecting area (cf. ASI, 2010). Due to the minor effects on heat gains, **opaque building elements will not be considered** within the calculation of solar gains (cf. *Chapter 4.5.2.2*).

4.4.2. Building Type and Occupancy

According to the European building classification, the building type describes the main occupancy of a building. This means that a residential building has to be mainly used for residential purposes (minimum 50%). All determination rules for the building properties are listed in the AGWR II (STATISTIK AUSTRIA, 2011).

The building type and the intensity of use is also an issue in ÖNORM 8110-5 (cf. ASI, 2011b). Intensity of use and other basic assumptions are standardized with user profiles for the different building types. It is also recommended to distinguish between residential, non-residential and other buildings, as this differentiation requires separate calculation paramteres.

Likewise, recent approaches used this attribute to model the thermal energy demand of cities (cf. BLESL, 2002; DORFNER, 2011; JONES, 2001; MAVROGIANNI, 2009; WEBSTER, 2009). The following building types are available and used (green) for the later energy model process:

Table 5 : Building Types and Occupancy (source: STATISTIK AUSTRIA, 2011)

	Used Building Types	**Residential**	**Non-Residential**
1	Single Family House	X	
2	Double Family or Row House	X	
3	Multi Family House	X	
4	Hotels		X
5	Offices		X
6	Whole Sales and Retail		X
7	Traffic and Telecommunication		X
8	Industrial Buildings and Storage Rooms		X
9	Public Buildings		X
	NOT Used Building Types		
10	Agricultural Buildings		
11	Garage		
12	Churches		
13	Pseudo-Building		
14	Other Building		

4.4.3. Climatic Aspects

Due to the fact that the local climate varies both temporarily (daily, monthly and yearly variation) and topographically (altitude, slope, aspect), it is necessary to use reference weather conditions (cf. ASI, 2011). Linked to the location, climatic characteristics can be assigned to each building.

4.4.3.1. Degree Days

Regarding ÖNORM B 8110-5 (ASI, 2011b), Austria is divided into seven climate regions and three altitude ranges (<750m, 750-1500m, >1500m). Graz, in the SE region, with an altitude between 347m (*Puntigam*) and 468m (*Mariatrost*), has a various amount of heating degree days (cf. *Chapter 3.1.2.4*), as shown in *Figure 21*.

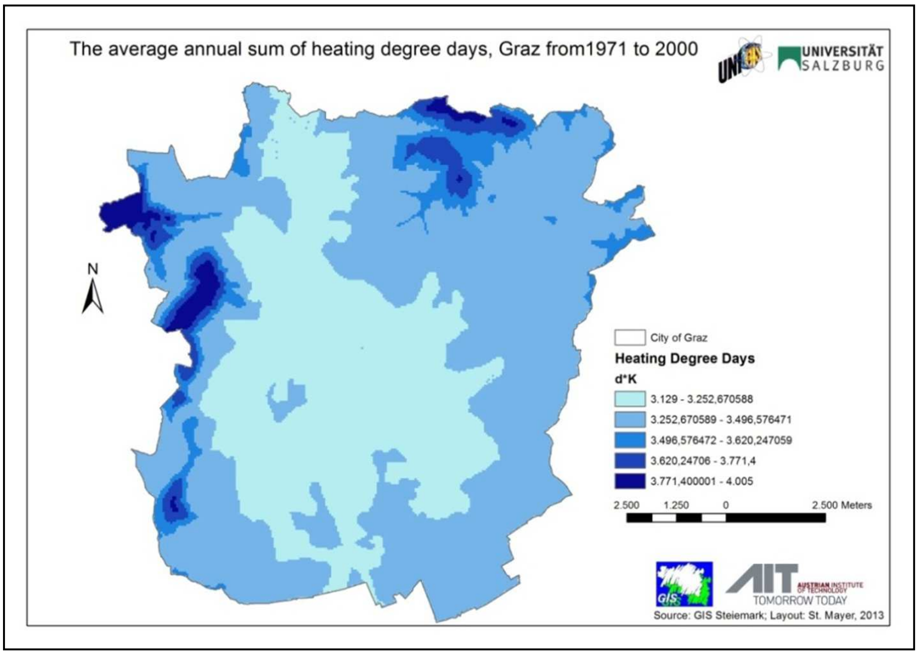


Figure 21: HDD of Graz (source: GIS Steiermark, 2013)

To assign the information of HDD to the building polygons, the following workflow is used. For all calculations, which refer to heating and cooling days only, a default value (211 for HD, cf. FREY, 1994) has been used.

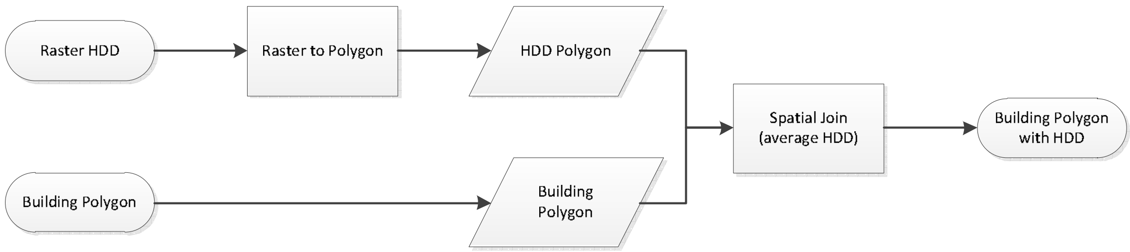


Figure 22: Workflow to assign the HDD to Building Polygons

Like mentioned above, there is no definition for cooling degree days in Austria. Hence, a default value for CDD (61) will be applied. This value is based on suggestions of PRETTENTHALER (2007) and the proximity of the described climate station to the area of investigation. The same source is taken for cooling days (34, cf. PRETTENTHALER, 2007).

4.4.3.2. Solar Irradiance (SI) – Orientation

Depending on season, solar radiation varies relatively to exposition, slope and altitude. This is measureable either as direct or diffuse solar irradiation in kWh/m². The latter also depends on the surface (albedo). Due to this dependency of SI on various factors, reference values based on ÖNORM B 8110-5 are used for further calculations (ASI, 2011b).

All reference values are provided as an average monthly sum of solar irradiation on the real surface. This means that two more factors have to be considered, in particular orientation and inclination of the transparent outdoor wall. To simplify the calculation process, it is assumed that all transparent building elements have an inclination of 90°. Rooftop-windows and other special cases are not considered. This workflow is applied to gather orientation and length for each external building element. A detailed description follows.

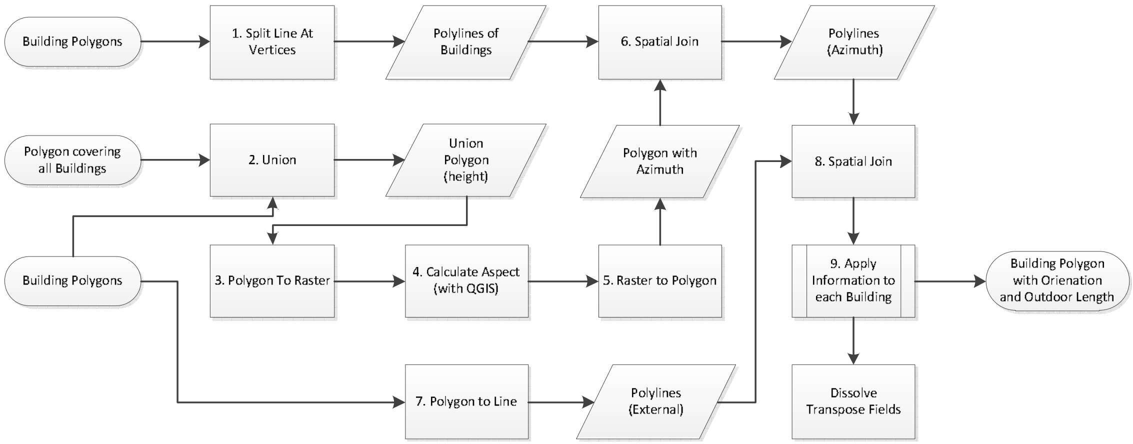


Figure 23: Workflow to obtain the Length for each Outdoor Building Element per Orientation

Gathering building orientation and external building element length:

1. To obtain each particular building orientation later on, all building polygons have to be split to polylines first. ArcGIS provides the function "*Split Line At Vertices*".

2. The aspect calculation requires a raster layer as the input data source. Thus, a polygon (e.g. "District"), which covers all buildings, is used to "*Union*" the original building shape. Building height and surrounding polygon (height=0) are further used to create the grid.

3. With "*Polygon to Raster*", a grid can be generated from the "Union Polygon" using value field ("height") and cell size (e.g. "1").

4. The "*aspect calculation*" with ArcGIS only provides the eight main cardinal points. Hence, QGIS (provides the real azimuth) is used for this step.

5. The function "*Raster to Polygon*" converts the grid back to polygons with the azimuth information.

6. A spatial join (average values) puts the azimuth information to the initially created polyline feature (ad 1.) of the building lines.
   (Note: As real azimuth values falsify average results (e.g. a polyline shares 57° and 285°), azimuths are summarized as follows (cf. to ASI, 2010).

Table 6: Assignment of Azimuth Values to Orientation, used for Solar Irradiance Calculation

lowAzimuth		Orienation		highAzimuth		
348.75°	>=	N	<	11.25°	=	**0°**
11.25°	>=	NNE	<	33.75°	=	**+/-22,5°**
33.75°	>=	NE	<	56.25°	=	**+/-45,0°**
56.25°	>=	ENE	<	78.75°	=	**+/-67,5°**
78.75°	>=	E	<	101.25°	=	**+/-90,0°**
101.25°	>=	ESE	<	123.75°	=	**+/-112,5°**
123.75°	>=	SE	<	146.25°	=	**+/-135,0°**
146.25°	>=	SSE	<	168.75°	=	**+/-157,5°**
168.75°	>=	S	<	191.25°	=	**+/-180,0°**
191.25°	>=	SSW	<	213.75°	=	**+/-157,5°**
213.75°	>=	SW	<	236.25°	=	**+/-135,0°**
236.25°	>=	WSW	<	258.75°	=	**+/-112,5°**
258.75°	>=	W	<	281.25°	=	**+/-90,0°**
281.25°	>=	WNW	<	303.75°	=	**+/-67,5°**
303.75°	>=	NW	<	326.25°	=	**+/-45,0°**
326.25°	>=	NNW	<	348.75°	=	**+/-22,5°**

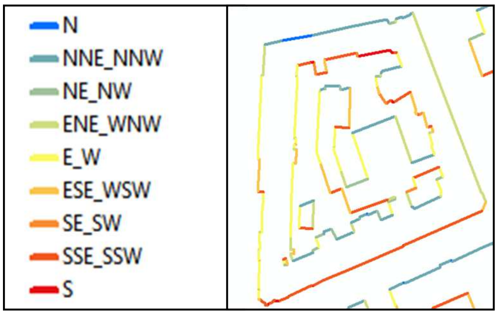


Figure 24: Results of the Aspect Calculation

7. Obviously, orientation information is only usable for external building elements. This information is associated with the "*Polygon To Line*" function (cf. *Chapter 4.4.1.3*).

8. A "*Spatial Join*" of the polyline features (point 6 and 7) combines both azimuth and adjacency information.

9. The transposition of the total (outdoor) length per cardinal point and building has to be done with Excel or Access, after a "dissolve" has been applied on the fields "*right_fid*", "*CardPoint*" and "*Shape_length (Sum)*" of the last spatial join.

This process describes how to obtain each building side length (polyline), referring to specified cardinal points. As it is important to know the window area, which is conferring to ÖNORM (ASI, 2010) 20% of the vertical building envelope, each polyline has to be multiplied with the building height and 0.2. Consequently, *Table 7* shows an example of the result.

Table 7: Window area per cardinal point and building (ArcGIS, 2014)

RIGH ID	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	SUM LENGTH	Shape Length	Shape Area
0	0	8.17578	3.53413	4.72732	0	0	2.9286	11.72222	0	31.08806	31.088055	41.675782
1	0	53.22877	0	0	0	15.03352	0	46.8766	0	115.13889	136.375074	799.462121
2	0	0	4.23068	25.29901	0	24.25864	0	5.05073	0	58.83906	58.839061	123.614699
3	0	11.82956	0	5.4534	0	4.93799	0	11.82461	0.51731	34.56287	34.562873	60.529031
4	0	9.97501	0	4.51627	4.70068	9.37873	0	7.83571	0	36.40641	36.406406	77.553391
5	0	27.96661	2.7268	4.60801	13.62609	17.48981	6.13781	24.4778	0	97.03294	97.032941	262.273173

Now, as climate relevant information has been attached to building polygons, the development of the proper and automated demand calculation can follow.

4.5. Implementation with Python and ArcGIS

This section describes the applied method of the overall thermal demand calculation with ArcGIS and Python, presented in chapter "*Theoretical Methodology*". Thermal losses and gains will be separated for individual calculations and summarized at the end of the process. Results and further analysis will be presented afterwards.

The whole calculation is implemented with Python programming language and requires geometrical and climatic building properties mentioned. Building polygons (feature class or shapefile) have to be available along with information about building properties (year of construction or renovation, building type, height, storeys), the area of individual building elements as well as degree days (HDD, CDD). All geometrical building properties will be calculated during the following processes.

Note: The following descriptions refer to the heating demand calculation only. Variances concerning cooling demand are annotated. All used python scripts can be found in *A*. *Figure 25* gives an overview about applied calculation structure.

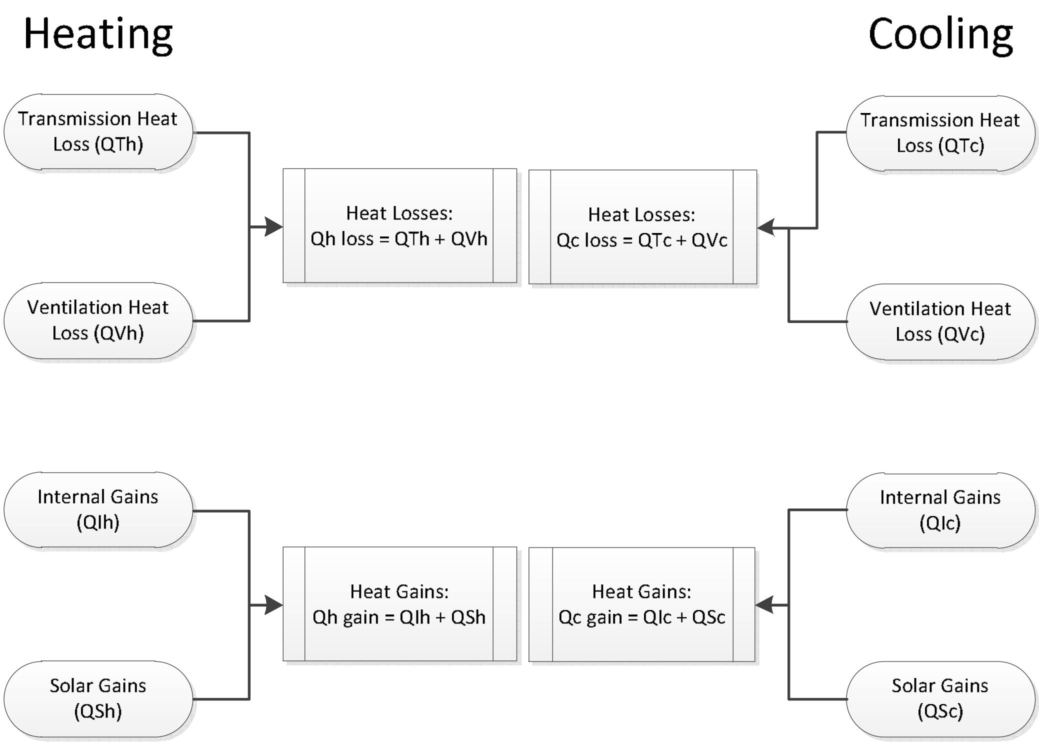


Figure 25: Workflow of Thermal Demand Calculation (Overview)

4.5.1. Thermal Losses

The following section deals with thermal losses both the transmission and the ventilation loss.

4.5.1.1. Transmission Heat Loss

At the beginning of the overall calculation, heat transmission loss is of interest. Due to the fact that different building elements have different U-values, depending on the year of construction or renovation, this approach applies default U-values for single family houses (SFH) and multifamily houses (MFH) built before 1980, and later on values determined by regulations of the Styrian federal state law (cf. OIB, 2011b, p.16-17; *A*). **All non-residential buildings are treated like MFH, for industrial buildings and stockrooms no window area is supposed.**

The used python script adds variable U-values, depending on building type and age, to different building elements (cf. *Table 8*) and then calculates the heat transfer coefficient (L_T) for heating (L_{Th}) and cooling (L_{Tc}). Additional parameters, like temperature correction factor per building element and conversion factor for degree days, will not be stored in the building table. The final output is the overall transmission heat loss for heating (Q_{Th}) and cooling (Q_{Tc}).

Table 8: Parameters and Values used for Transmission Heat Loss Calculation

Building properties	**Description**	**Values**
Usage	Mainly usage (e.g. family house, office, hotel, …)	1,2,3,4, …
Age	Year of construction/renovation	e.g. <1944, <1960, <1980, …
Building elements		**Equivalent Area**
KD	Ceiling to unconditioned basement	Polygon shape
OD	Ceiling to unconditioned attic	Polygon shape
AW	Outdoor wall without window area	Vertical building envelope minus window area
FE	window area	20% of vertical building envelope
U Values	**Description**	**Reference**
U_KD	Depends on year of construction and building type; cf. Appendix	OIB, 2011b, p.16-17; Appendix
U_OD		
U_AW		
U_FE		
Temperature Correction factor *	**f(i,h)**	**f(i,c)**
Ceiling to unconditioned attic	0.9	0
Ceiling to unconditioned basement	0.7	0.7
Outdoor wall	1	1
Climatic factor	**Description**	**Value**
HDD/HD	avg_grid_code per building/default value	e.g. 3467.5/211
CDD/CD	Default value	61/34
Conversion factor	for 24 hours per day	0.024
		***(cf. ASI, 2010; Appendix)**

The figures below show the variability of the process, as the temperature correction factor per building element can be modified. Modifications concerning default U-values have to be taken in the python script (cf. *Chapter 3.2.3.1*, *A*).

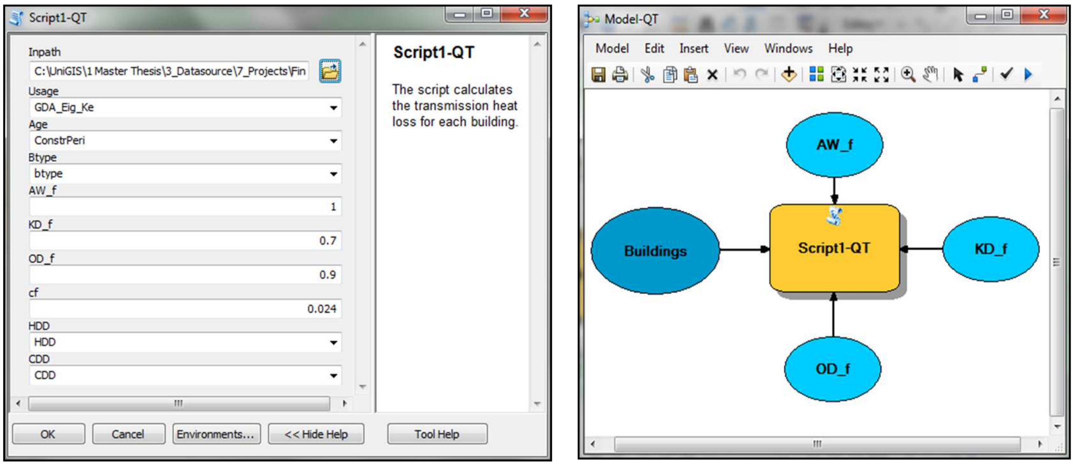


Figure 26: Script Input for Transmission Heat Loss Calculation

4.5.1.2. Ventilation Heat Loss

To determine the total amount of heat loss by ventilation (Q_V), it is first of important to identify the ventilation loss coefficient (L_V), which also depends on the heat capacity and density of air. The only measure derived from building geometry is the energy-related air volume (V_V), as described in *Chapter 4.4.1.2 "Conditioned Gross/Net Volume*". For all kind of residential buildings, the air exchange rate through ventilation is considered (1/h =0.4), which conforms to a natural window ventilation. For other buildings, the air exchange rate for ventilation and AC technology depends on building type and is based on suggestions from ÖNORM B 8110-5 (2011b, cf. *A*).

Table 9: Parameters and Values used for Ventilation Heat Loss Calculation

Parameters*	Description	Value
$c_{p,L} * \rho_L$	Volume sourced heat capacity of air (Wh/m³K)	0.34
n_L	Effective Air Exchange Rate (1/h)	e.g. 0.4*
Building Property		
GFA	Gross Floor Area	Shape Area
Floor	Number of Storeys	1,2,3,4,…
Usage	Main usage (e.g. family house, office, hotel, …)	1,2,3,4,…
RoomHeight	Default value*	2.6
VV	Energy-related Air Volume (m³)	e.g. 43536.2
Climatic factor		
HDD/HD	avg_grid_code per building/default value	e.g. 3467.5/211
CDD/CD	Default value	61/34
Conversion factor	For 24 hours per day	0.024
		***(cf. ASI, 2010)**

Mandatory attributes to calculate the energy-related air volume are the building footprint, the number of floors and the room height (2.6 m are assumed). Concerning the air exchange rate, a building type is mandatory. The implementation allows modifications on room height, effective air exchange rates can be modified in the python script only.

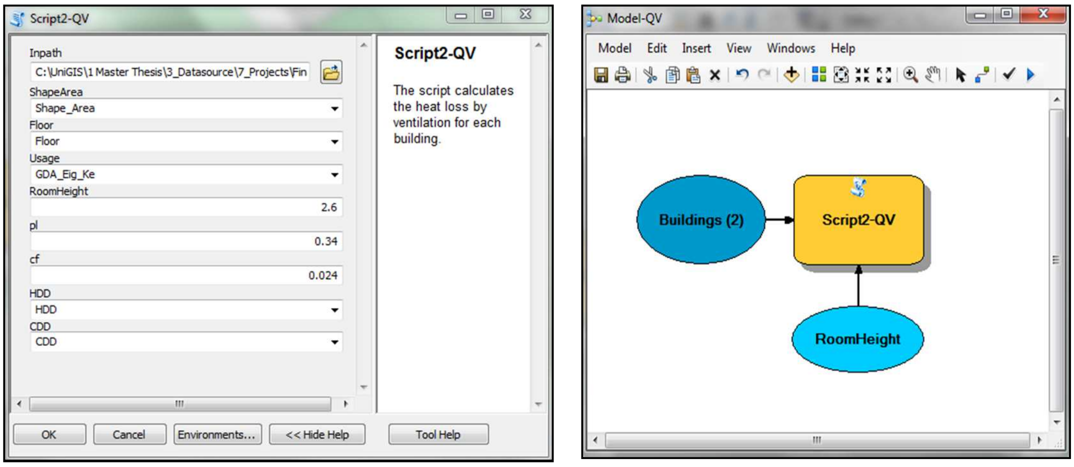


Figure 27: Script Input for Heat Loss Calculation by Ventilation

The python process assigns the proper air exchange rate to each building (cf. ASI, 2011b) and calculates the energy-related air volume (*VV*), followed by the heat loss coefficient by ventilation (LV). The latter has to be done both for heating and cooling, which leads to the overall ventilation heat loss for heating (Q_{Vh}) and cooling (Q_{Vc}) (cf. *Chapter 3.2.3.2, A*).

4.5.2. Thermal Gains

This part will describe the implementation of thermal gains both internal and solar.

4.5.2.1. Internal Heat Gain

As mentioned in the chapter on "*Method*", this approach relates to the simplified method and uses standardized values for internal heat gain (q_i) per m², depending on the building type. The amount of heating/cooling days and the energy reference area (A_R) are mandatory values.

Table 10: Parameters and Values used for Internal Heat Gain Calculation

Parameter*	Description	Value
q_i	Internal Heat Gain (W/m²)	e.g. 3.75
Building Property		
AR	Gross Floor Area	Shape Area
ST	Number of Storeys	1,2,3,4,…
Usage	Type of Building	0, -1
Climatic factor		
HD	avg_grid_code per building/default value	211
CD	Default value	34
Conversion factor	For 24 hours per day	0.024
		***(cf. ASI, 2010)**

Both heating and cooling days can be modified in the ArcToolbox module. Building footprint area and number of floors are taken from the input file. All default values for internal heat gain have to be changed in the python script code.

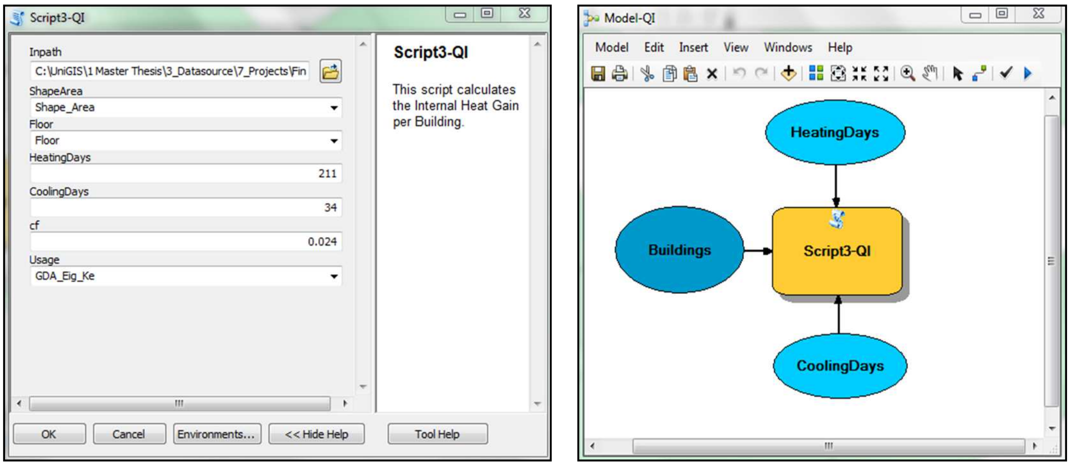


Figure 28: Script Input for Internal Heat Gain Calculation

The python script adds all required fields (*qh*, *qc*, *AR* and results), sets default values for internal heat gain per m² in case of heating (*qh*) and cooling (*qc*) and calculates the energy reference area (*AR*). Subsequently, internal gains for heating (*QIh*) and cooling (*QIc*) will be calculated (cf. *Chapter 3.2.4.1*, *A*).

4.5.2.2. Solar Gains

The second and climate-depending thermal gain is about solar irradiation on glazed or transparent building areas. First of all, the solar effective area (A_g) has to be calculated**,** which refers to the glass ratio (f_g) of a window and is by default 70% of the window area.

The solar effective g-value (g_w) contains non-perpendicular radiation (0.9), dirt (0.98) and the solartransmittance value *g* for clear glass. This approach uses a default g-value of 0.75, which refers to uncoated double isolation glazing. Different g-values for different types of glass are presented in ÖNORM B 8110-6 (ASI, 2010).

The usage of the shading reduction factor corresponds to the description in *Chapter 3.2.4.2* “*Solar Gains*” (cf. simplified method, ASI, 2010).

Table 11: Parameters and Values used for Solar Heat Gain Calculation

Parameter*	Description	Value
A_g	Solar Effective Area (m²) per Orientation	Window Area * 0.7
g_w	Solar effective g-value ($g_w = 0.9 * 0.98 * g$)	g = 0.75 (default)
Climatic factor		
F_s	Shading Reduction Factor (SFH/MFH)	0.85/0.75/(1 for cooling)
I_j	Solar Irradiance on real surface (kWh/m²/a) during Heating/Cooling Season	e.g. 428.3
Transposition Factor	Inclination of A_g and Orientation (cardinal points) of Solar Effective Area	Inclination → 90°; Orientation → 0°, +/-22,5°, +/-45,0°, +/-67,5°, +/-90,0°, +/-112,5°, +/-135,0°, +/-157,5°, +/-180,0°
		***(cf. ASI, 2011b)**

For this calculation process, an external csv file with information on solar irradiance (kWh/m²) per month and orientation (see *Table 12*) will be used. This csv file will be loaded into a python dictionary, so that every combination of month and cardinal point can be queried later on.

Table 12: Monthly Solar Irradiation (kWh/m²) per Orientation (ASI, 2011b)

ID	January	February	March	April	May	June	July	August	September	October	November	December
N	13.11	21.08	28.36	39.48	55.21	58.99	59.41	44.32	35.63	23.81	13.21	9.6
NNW_ NNE	13.11	21.08	30.23	43.71	61.53	65.39	66.64	50.03	37.86	23.81	13.21	9.6
NW_NE	13.78	22.62	35.03	50.76	70.16	74.12	75.87	59.9	43.3	26.87	13.92	9.94
WNW_ENE	15.72	26.16	42.43	59.22	79.55	82.66	85.31	71.33	51.09	32.66	16.01	11.36
W_E	19.51	32.14	52.12	67.68	88.18	88.48	93.14	81.71	60.37	40.86	20.14	14.63
WSW_ESE	25.66	40.81	60.88	73.61	91.63	89.06	94.34	87.43	68.16	50.27	26.63	20.66
SW_SE	31.95	49.49	68.8	77.27	91.63	86.15	91.93	89.68	74.97	59.04	33.35	26.91
SSW_SSE	37.06	56.49	74.95	78.96	89.71	81.69	87.32	89.33	79.92	66.04	38.9	31.97
S	39.63	60.16	78.39	78.96	87.41	77.61	81.9	87.25	82.14	70.14	41.85	34.39

At the beginning of the calculation process, new fields will be created for the solar effective areas per orientation (*j*). To obtain the values of these solar effective areas, the results from the aspect calculation (cf. *Chapter 4.4.3.2*) will be multiplied with 0.7. The utilization of the correct shading reduction factor will be accomplished as described, depending on the building type.

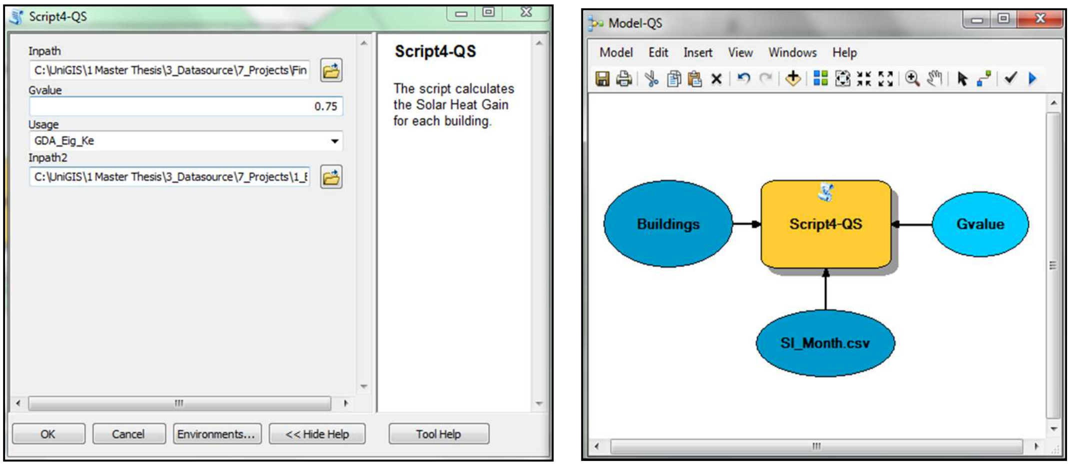


Figure 29: Script Input for Internal Heat Gain Calculation

To distinguish between heating and cooling season, this approach applies solar irradiation values from September to April to the heating season and values from May to August to the cooling season, which can be modified in the python script. Finally, the solar gains for heating season (*QSh*) and cooling season (*QSc*) will be calculated (cf. ASI, 2011b, *A*).

4.5.3. Annual and Specific Demand

Now, the results of the individual calculations for gains and losses have to be combined in order to obtain the total and the specific heating and cooling demand per year. Hence, a last script is used to generate the final outcomes. All individual gains and losses of the previous calculations are required, with both the gross floor area and a utilization factor (η).

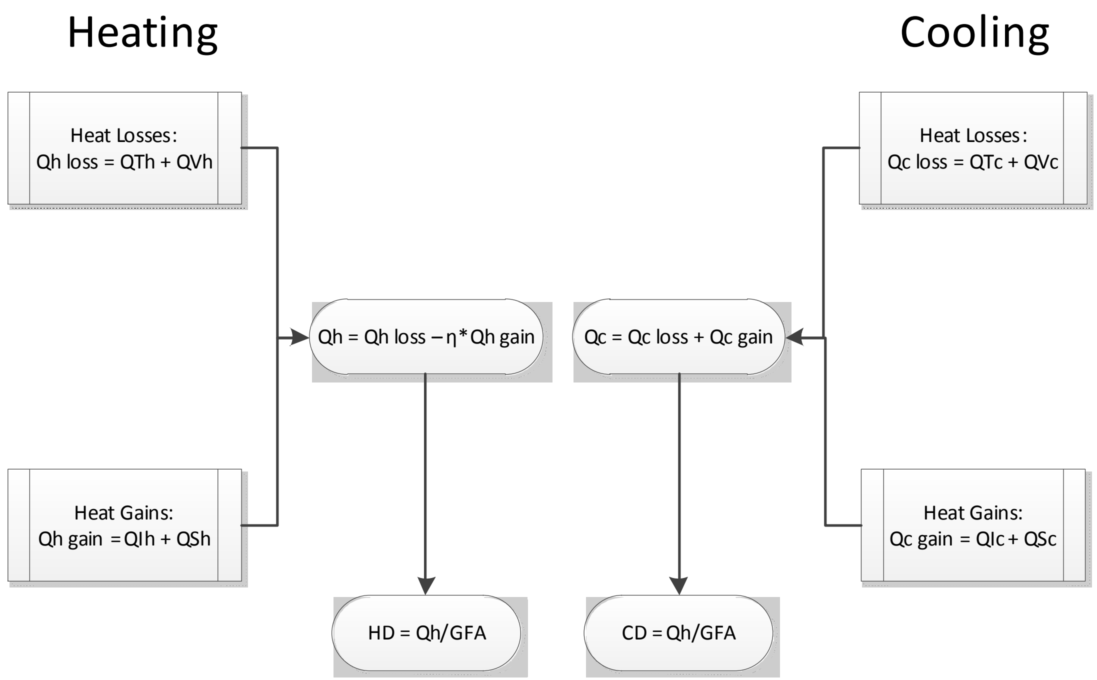


Figure 30: Overview of the Specific Heating and Cooling Demand Calculation

In case of the heating demand only, it is necessary to apply a utilization factor (η) to combine heat losses and gains. This utilization factor could be between 0.9 for lightweight constructions and 1 for massive old buildings (cf. OIB, 1999). This approach uses a value of η = 0.95, because of the diversity of the building structure in the total area of interest.

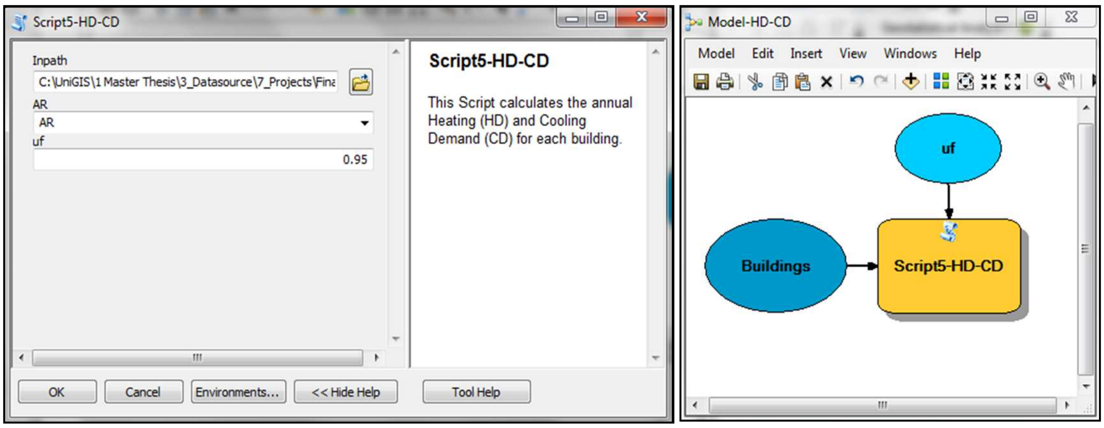


Figure 31: Script Input for total Heating/Cooling Demand

Within the first step, the python script sums up all individual losses and gains for heating and cooling. Then, to obtain the annual heating demand (Q_h), the sum of internal heat gain (Q_I) and solar heat gain (Q_S) will be subtracted from the sum of transfer loss (Q_T) and ventilation loss (Q_V), whereas the utilization factor η_h is applied for all gains.

$$Q_h = (Q_T + Q_V) - \eta_h * (Q_S + Q_I)$$

The calculation of the annual cooling demand (Q_c) looks a little different, because all gains operate like losses and have to be added to them. Therefore, no utilization factor is necessary.

$$Q_c = (Q_T + Q_V) + (Q_S + Q_I)$$

Now, the total amount of heating and cooling demand is available. But at the end, the results shall also be comparable. As all buildings have different shapes and sizes, the specific heating (S*HD*) and cooling demand (S*CD*) will be used. According to ÖNORM B 8110-6 (ASI, 2010), the specific heating and cooling demand have to be calculated as follows.

$$SHD, SCD = \frac{Q_{h,c}}{AR}$$

SHD/SCD ... Specific Heating/Cooling Demand (kWh/m²a)
Qhc ………..Annual Heating/Cooling Demand (kWh/a)
AR…………..Energy Reference Area (m²)

4.5.4. Visualization of Results

The last part of the demand model process contains the conversion of the building polygon information of heating/cooling demand into the required raster format, mentioned at the beginning of this master thesis (cf. *Chapter 1* "*Introduction*").

Thus, building polygon shapes will be converted with the ArcGIS function "*Feature To Point*", which creates a point in the center of each polygon. Now it is possible to generate a raster with the required information. *Figure 32* shows the configuration for the average amount of specific heating demand (*SHD*, kWh/m²a) within 125 meters. Besides, the configuration to obtain the sum of the annual heating demand (*Qh*, kWh/a) is shown. This can be applied likewise for cooling demand values. The last figure in this chapter shows the model process overview for the result raster generation.

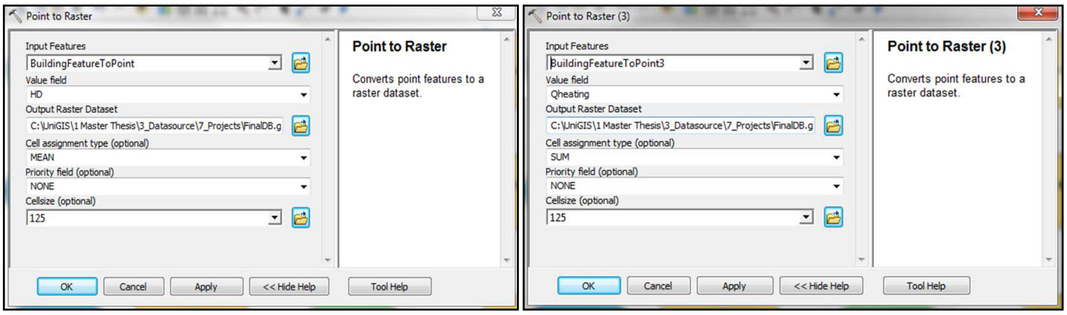


Figure 32: Script Input for the "Point To Raster" Conversion

At the end, the total amount of annual heating/cooling (*Qh/Qc*) demand will be divided through the total amount of the Energy Reference Area (AR in m²) within the 125m raster, to obtain the average SHD/SCD per raster.

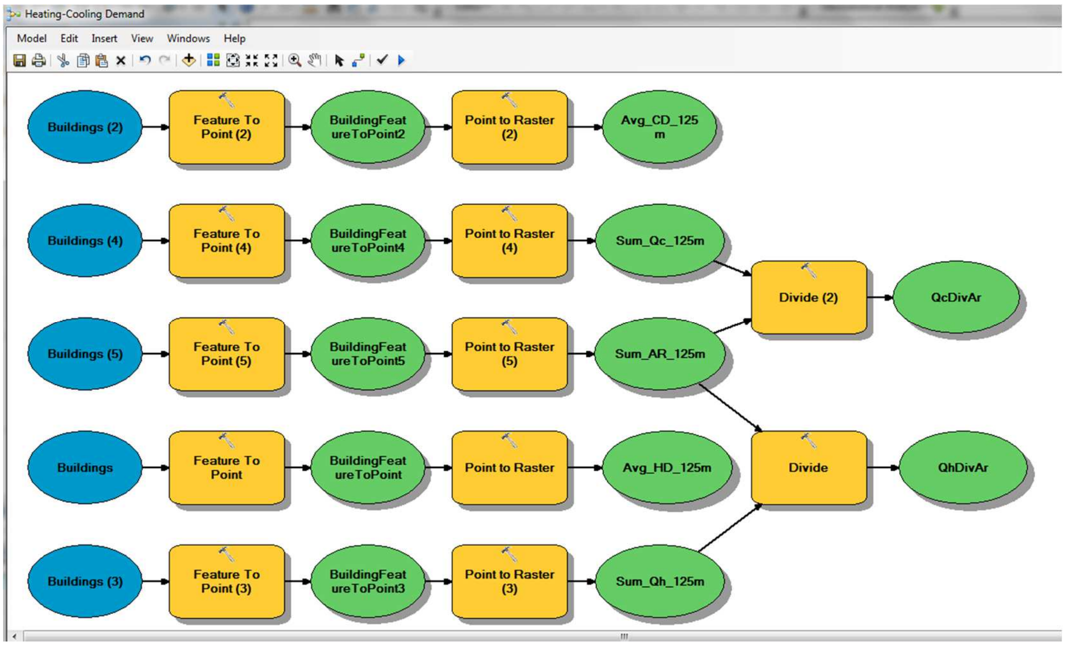


Figure 33: Model for the Raster Visualization Process

5. RESULTS

Previously, the practical approach described how to model the thermal demand of buildings. The process was split into a separate calculation of the thermal gains and thermal losses. Both are summarized in the end, in order to obtain the annual thermal demand for heating and cooling. This section deals with the final outcomes for the two case studies (*Inner City*, *Liebenau*), starting with the individual process results for the heating and cooling demand.

Due to the fact that buildings differ in size, shape, orientation, occupancy and many other properties, the following result descriptions refer to the specific thermal demand (specific heating/cooling demand, SHD/SCD) of buildings in kWh/m²a, in order to make them comparable. The focus is set on the average specific demand per building type and construction period for the individual results and subsequently the total yearly demand of heating (SHD) and cooling (SCD) in kWh/m²a for every building.

In the beginning, some building statistics of both districts shall help to figure out required information and analyse the calculated results later.

5.1. Building Statistics

The chapter "*Project Description*" provided us with a short introduction into the area of investigation and indicated the differences between both districts, especially concerning building structure and population density. The following table gives an overview about the amount of considered buildings per construction period (before 1919, 1919-1944, 1945-1960…) and building type (Usage). Due to the small amount, buildings constructed after 2010 were added to the construction period of 2010.

Table 13: Count of Building Type within Construction Period and Area of Investigation (source: City of Graz, 2013)

Count of Usage	Column Labels									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	245	99	167	13	147	80	2	15	26	794
1944	293	29	10	2	18	3		14	1	370
1960	538	56	41	2	27	14	4	11	10	703
1970	529	40	35	5	8	7		13	2	639
1980	418	67	40	3	27	21	1	33	5	615
1990	168	23	16	4	8	8		11	4	242
2000	140	17	11	1	3	4		14	1	191
2010	345	45	29	5	15	10	3	24	3	479
Grand Total	**2676**	**376**	**349**	**35**	**253**	**147**	**10**	**135**	**52**	**4033**

This table gives a clear picture of the most relevant building types, which are mainly residential buildings. It has to be noted that the category "*Double Family and Row Houses*" is also assigned to some old buildings of the *Inner City* district of Graz. The amount of hotels, public buildings and buildings referring to the traffic and telecommunication sector is rather small. For the "*Traffic/Telecom.*" category no data exists in the period of 1944, 1990 and 2000.

The following *Figure 34* shows the differences concerning construction period of buildings in both districts. The *Inner City* district or "*Altstadt*" Graz was mainly built before 1919. A second but minor building period can be noted between 1944 and 1960. However, the main building period in *Liebenau* district refers to "*Single Family Houses*" (SFH) after 1944 (WWII). Other building types were constructed in a rather harmonised way in *Liebenau*, most of them between the fifties and seventies.

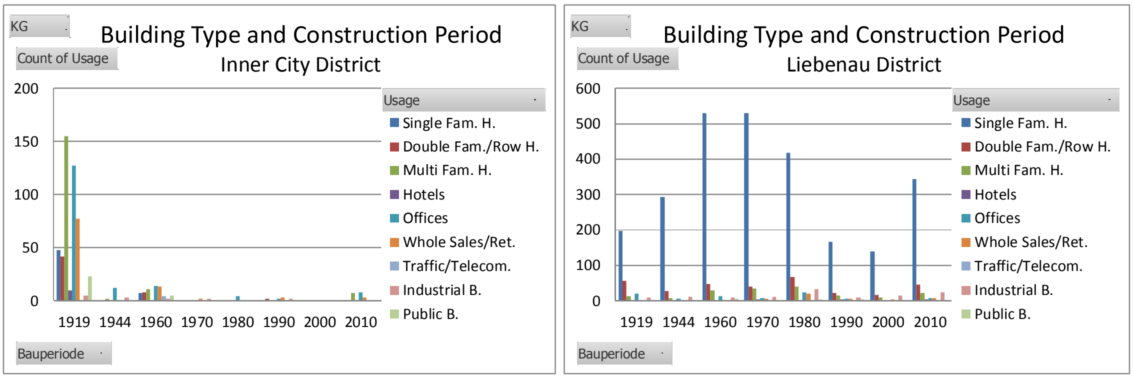


Figure 34: Number of Building Types in Construction Period; Inner City (l.), Liebenau District (r.) (source: City of Graz, 2013)

5.2. Individual Results - Heating Demand

The following section describes the individual results of the heating demand calculations.

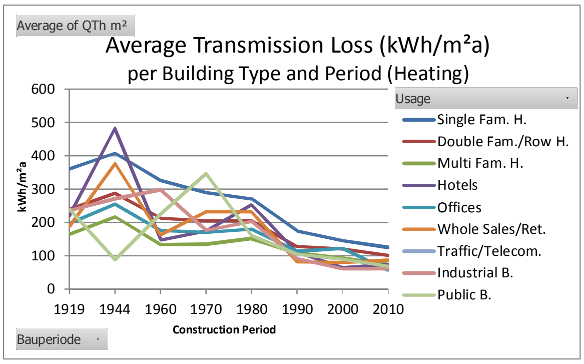
5.2.1. Transmission Loss ($\boldsymbol{Q_{Th}}$)

Table 14 summarizes the results of the transmission heat loss (Q_{Th}) in kWh/m²a per construction period and building type. SFHs seem to have the highest average of all building types, with a general decrease in the near past. Values from categories with a low value density have to be evaluated slightly different.

Table 14: The Average Transmission Loss ($\boldsymbol{Q_{Th}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QTh m²	Column Label									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	359.80	240.32	164.57	219.04	196.57	188.33	336.10	236.34	239.11	247.70
1944	407.36	287.73	217.45	482.48	254.67	376.74		271.23	88.50	379.57
1960	325.51	213.27	134.08	147.44	176.36	162.25	357.96	298.30	225.70	294.26
1970	290.17	205.36	134.95	174.15	170.54	232.06		176.57	346.14	271.18
1980	270.77	204.89	152.07	252.35	180.32	232.05	146.80	203.46	159.87	245.77
1990	174.80	127.67	107.50	110.33	113.66	82.18		90.83	105.18	154.75
2000	145.08	120.32	93.52	64.51	122.13	79.77		61.14	90.39	131.32
2010	125.27	101.79	73.84	74.38	56.15	87.01	49.13	61.80	69.08	112.45
Grand Total	**277.36**	**201.02**	**145.71**	**188.94**	**184.16**	**182.40**	**239.82**	**170.16**	**207.16**	**244.19**

Figure 35 visualizes the content of this table. It proves that SFHs have the highest values in general, but also shows that "*Hotels*" have the highest average result value in the construction period between 1919 and 1944. The same is valid for MFHs built between 1960 and 1970. Off the 1990 period, all average building type values are below 200 kWh/m²a.



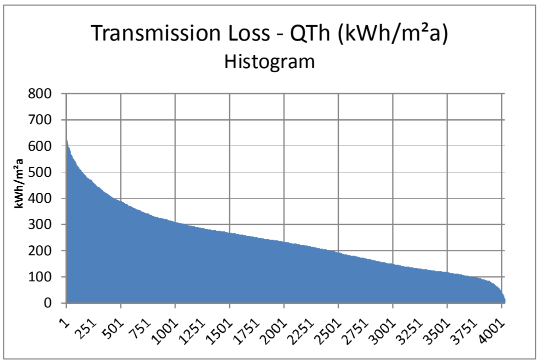


Figure 35: Average Transmission Loss ($\boldsymbol{Q_{Th}}$) per Building Type and Construction Period

Figure 36: Histogram of the Transmission Loss ($\boldsymbol{Q_{Th}}$) in case of Heating

(source: City of Graz, 2013)

Figure 36 shows a histogram of the specific transmission loss (Q_{Th}) per Building (x-axis). All results are in a descending order. The highest values refer to the category "*Single Family House*", built before 1944. It is remarkable that many of the buildings have both a very low characteristic length value (in the range of 0.5) and building footprint area (< 70 m²). Nearly 2000 values are between 200 and 400 kWh/m²a. The range of values below 100 kWh/m²a refers to all building types, but most of them built after 1990.

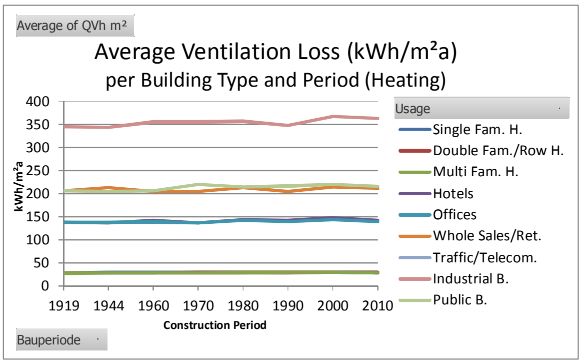
5.2.2. Ventilation Loss ($\boldsymbol{Q_{Vh}}$)

The results of the ventilation loss (Q_{Vh}) in kWh/m²a look quite different, also because default values are used for air exchange rate per building type. The highest values per m² are assigned to the category "*Industrial Buildings*" (>300 kWh/m²a). All residential buildings have an assigned ventilation loss of about 28 kWh/m²a. These values do not change very much during the construction periods due to the applied method with fixed air exchange rates.

Table 15: The Average Ventilation Loss ($\boldsymbol{Q_{Vh}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QVh m²	Column Labels									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	28.10	28.14	27.49	137.72	137.88	205.74	147.11	345.86	205.70	80.11
1944	28.72	28.29	27.80	136.84	138.16	213.00		344.49	205.61	48.49
1960	28.81	28.23	27.73	142.02	138.48	205.51	137.01	356.18	206.51	45.02
1970	29.16	28.80	28.37	136.92	136.90	205.42		355.93	220.48	40.46
1980	28.97	28.72	28.65	143.62	142.60	212.98	136.97	357.29	214.53	60.05
1990	29.24	28.75	29.03	142.01	139.47	205.46		348.09	216.83	58.11
2000	28.94	29.17	29.04	147.11	143.76	214.92		367.65	220.67	61.12
2010	28.84	28.87	28.42	141.40	139.03	211.49	136.98	363.42	216.08	55.87
Grand Total	**28.87**	**28.51**	**27.95**	**139.59**	**138.62**	**207.51**	**139.02**	**355.89**	**209.01**	**56.65**

The differences can be explained due to the different amount of heating degree days. As they vary within the district areas, depending on the location of each building, the total specific ventilation loss (kWh/m²a) per building varies too (see *Figure 21*). This difference is really small but clarifies the information given in the ventilation loss table and histogram. The dominant amount of residential buildings (about 29 kWh/m²a values) is displayed in the histogram (*Figure 38*).



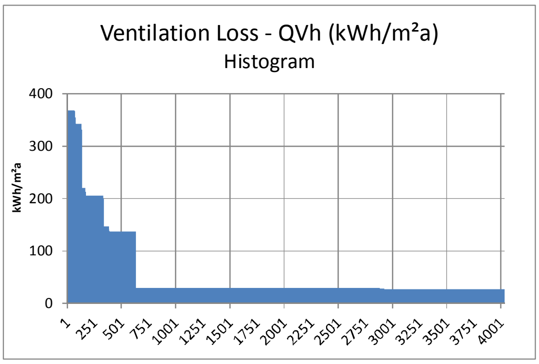


Figure 37: Average Ventilation Loss (Q_{Vh}) per Building Type and Construction Period

Figure 38: Histogram of the Ventilation Loss (Q_{Vh}) in case of Heating

(source: City of Graz, 2013)

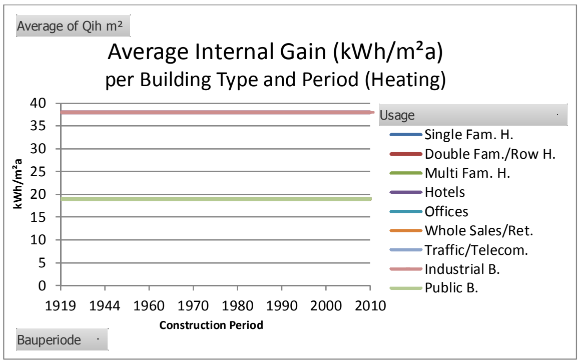
5.2.3. Internal Gain (Q_{Ih})

All results in this category are subsequent, constant internal heat gains in W/ m² (*qi*) and heating days (211). The amount of heating days was used for all buildings, a distinction was made concerning *qi*. While for "*Industrial Buildings*" and "*Hotels*" a value of 7.5 W/m² has been used, for the other building usages 3.5W/m² has been assigned.

Hence, the summarized table shows only two different values per building type and construction period. As a conclusion, it can be determined that an amount of 211 heating days with 7.5 W/m² of internal heat gain per m² leads to about 38 kWh/m²a of heat gains per year. In comparison, about 19 kWh/m²a will be obtained with 3.5 W/m². According to this, both figures below provide the analogous output.

Table 16: The Average Internal Gain (Q_{Ih}) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of Qih m²	Column Labels									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	18.99	18.99	18.99	37.98	18.99	18.99	18.99	37.98	18.99	19.66
1944	18.99	18.99	18.99	37.98	18.99	18.99		37.98	18.99	19.81
1960	18.99	18.99	18.99	37.98	18.99	18.99	18.99	37.98	18.99	19.34
1970	18.99	18.99	18.99	37.98	18.99	18.99		37.98	18.99	19.52
1980	18.99	18.99	18.99	37.98	18.99	18.99	18.99	37.98	18.99	20.10
1990	18.99	18.99	18.99	37.98	18.99	18.99		37.98	18.99	20.17
2000	18.99	18.99	18.99	37.98	18.99	18.99		37.98	18.99	20.48
2010	18.99	18.99	18.99	37.98	18.99	18.99	18.99	37.98	18.99	20.14
Grand Total	**18.99**	**18.99**	**18.99**	**37.98**	**18.99**	**18.99**	**18.99**	**37.98**	**18.99**	**19.79**



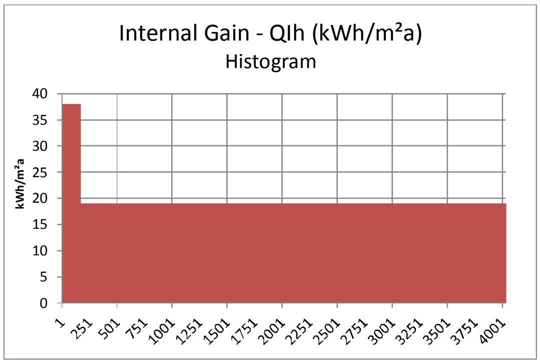


Figure 39: Average Internal Gain ($\boldsymbol{Q_{Ih}}$) per Building Type and Construction Period

Figure 40: Histogram of the Internal Gain ($\boldsymbol{Q_{Ih}}$) in case of Heating

(source: City of Graz, 2013)

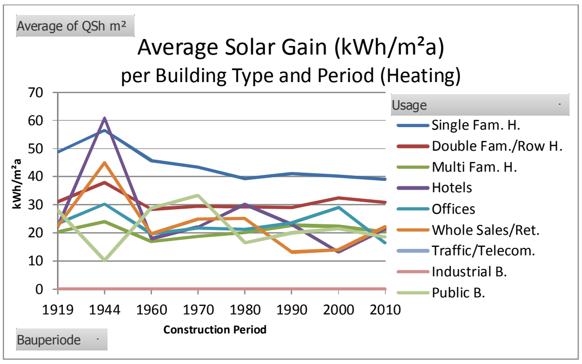
5.2.4. Solar Gain ($\boldsymbol{Q_{Sh}}$)

As already indicated in the chapter "*Project Description*" (see chapter *4.4.3.2*), the solar gain (Q_{Sh}) mainly depends on the solar effective area per orientation. For the heating season, solar irradiation values per month were taken from September to April. The highest average solar gain value was detected for "*Hotels*" of the construction period of 1944. However, only two values were used for the calculations in this category.

Table 17: The Average Solar Gain ($\boldsymbol{Q_{Sh}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QSh m²	Column Labels									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	48.70	31.13	20.29	22.01	23.17	22.42	31.13	0.00	28.02	31.08
1944	56.44	37.89	24.08	60.84	30.25	44.91		0.00	10.24	50.51
1960	45.65	28.40	16.84	17.91	19.69	19.64	29.59	0.00	28.84	39.96
1970	43.41	29.48	18.70	22.06	21.67	24.96		0.00	33.32	39.63
1980	39.32	29.17	20.11	30.18	21.25	25.05	14.14	0.00	16.54	33.31
1990	41.00	29.00	22.71	23.04	23.55	13.12		0.00	19.99	34.65
2000	40.13	32.38	22.26	13.19	29.09	14.00		0.00	21.41	34.51
2010	39.06	30.87	20.32	21.48	16.43	22.20	10.58	0.00	18.52	33.65
Grand Total	**44.25**	**30.62**	**19.99**	**24.49**	**22.73**	**22.36**	**22.65**	**0.00**	**25.64**	**36.79**

Generally, it seems that SFHs have the highest values, since they also have the highest window area ratio (the GFA serves as reference). The lowest values are detected for MFH with an average of nearly 20 kWh/m²a. No window area was assumed for industrial buildings. The histogram displays the distribution of the values, starting with a maximum of 105 kWh/m²a. More than half of the values (2021) are between 50 and 30kWh/m²a per building.



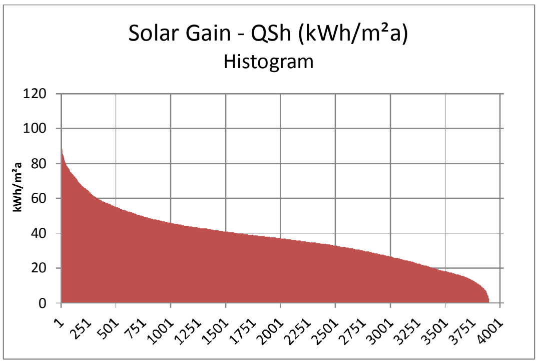


Figure 41: Average Solar Gain ($\boldsymbol{Q_{Sh}}$) per Building Type and Construction Period

Figure 42: Histogram of the Solar Gain ($\boldsymbol{Q_{Sh}}$) in case of Heating

(source: City of Graz, 2013)

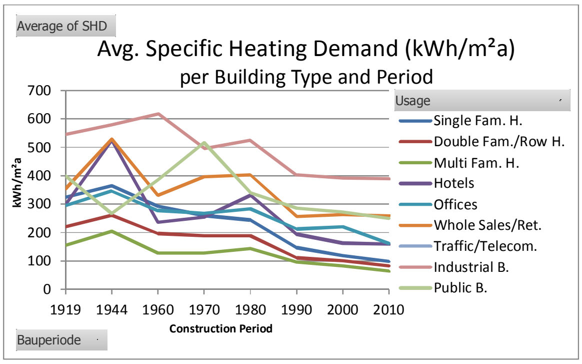
5.2.5. Specific Heating Demand

As already mentioned, the specific demand (see chapter *4.5.3*) is used to compare different buildings. The following table gives an overview of the average specific heating demand (SHD) in kWh/m²a per building type and construction period. The highest average values were detected for "*Industrial Buildings*" (490 kWh/m²a), followed by "*Public Buildings*" (374 kWh/m²a) and "*Whole Sales and Retail*" (351 kWh/m²a). Residential buildings have generally low values, the lowest refer to the category "*Multi Family House*" (137 kWh/m²a).

Table 18: The Average Specific Heating Demand ($\boldsymbol{Q_h}$) per Building Type and Construction Period (source: City of Graz, 2013)

Average of SHD	Column Labels									
Row Labels	**Single Fam. H.**	**Double Fam./Row H.**	**Multi Fam. H.**	**Hotels**	**Offices**	**Whole Sales/Ret.**	**Traffic/Telecom.**	**Industrial B.**	**Public B.**	**Grand Total**
1919	323.59	220.84	154.75	299.76	294.40	354.73	435.60	546.12	400.15	279.60
1944	364.42	261.99	204.33	525.44	346.05	529.04		579.64	266.35	361.26
1960	292.91	196.49	127.78	236.37	278.10	331.07	448.82	618.39	386.77	282.94
1970	260.05	188.12	127.51	254.03	268.82	395.73		496.41	516.92	255.45
1980	244.34	187.85	143.58	331.22	284.69	403.19	252.29	524.67	340.64	255.09
1990	147.05	110.83	96.92	194.37	212.72	257.13		402.83	284.98	160.79
2000	117.86	100.69	83.38	163.01	220.21	263.35		392.71	272.68	140.20
2010	98.97	83.29	64.92	159.29	161.53	259.38	158.01	389.14	249.53	117.22
Grand Total	**246.15**	**182.40**	**136.62**	**269.18**	**283.15**	**350.62**	**339.28**	**489.96**	**373.77**	**247.09**

Figure 43 visualizes these average values (SHD) per building type and construction period. It can be noted that generally industrial buildings have the highest heating demand with an increase during the construction period until 1960. Public buildings have the highest SHD by construction period until the end of the sixties. For all other building types, SHD started to decrease constantly from the period of 1944 onwards.



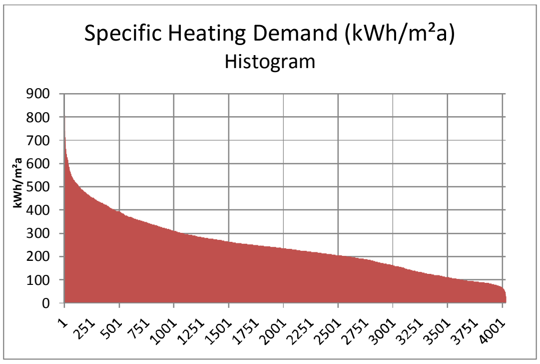


Figure 43: Average Specific Heating Demand (SHD) per Building Type and Construction Period

Figure 44: Histogram of the Specific Heating Demand (SHD)

(source: City of Graz, 2013)

The second figure shows the histogram of all used datasets, arranged by SHD in descending order. By analysing the "Top 10" values, it has been shown that they refer to "*Industrial Buildings*" only, the first among others belongs to "*Whole Sales and Retails*". Most of the SHD values (2124) range between 200 and 400 kWh/m²a. On the right side of the histogram, low SHD values are displayed, which mainly refer to “*Multi Family Houses*”.

5.3. Individual Results - Cooling Demand

This section provides information about the individual results of the cooling demand calculations.

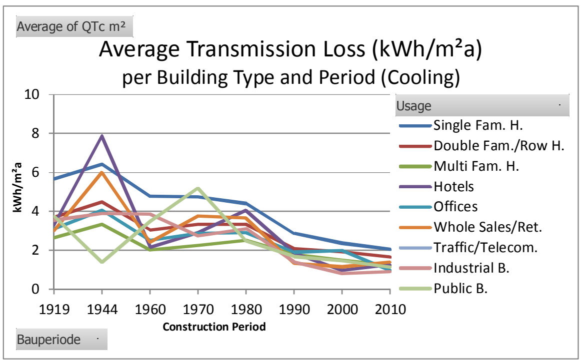
5.3.1. Transmission Loss ($\boldsymbol{Q_{Tc}}$)

In case of cooling, the results of the transmission loss (Q_{Tc}) calculation are much lower. SFHs still have the highest average results of all building types (4.38 kWh/m²a) with a general decrease from 6.43 kWh/m²a in 1944 to 2.06 kWh/m²a in 2010. All other categories have average transmission loss values between 2.5 and 3.24 kWh/m²a.

Table 19: The Average Transmission Loss ($\boldsymbol{Q_{Tc}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QTc m²	Column Labels								
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	5.68	3.69	2.66	3.30	3.11	3.01	4.68	3.55	3.77	3.91
1944	6.43	4.49	3.33	7.89	4.07	6.00		3.89	1.40	5.97
1960	4.77	3.05	2.02	2.17	2.52	2.43	4.54	3.86	3.49	4.30
1970	4.74	3.34	2.27	2.91	2.88	3.76		2.76	5.19	4.43
1980	4.40	3.33	2.50	4.05	2.91	3.65	2.32	3.12	2.48	3.98
1990	2.87	2.09	1.78	1.86	1.91	1.33		1.41	1.68	2.54
2000	2.37	1.93	1.51	0.97	1.99	1.16		0.82	1.47	2.12
2010	2.06	1.65	1.23	1.26	0.97	1.39	0.78	0.90	1.14	1.84
Grand Total	**4.38**	**3.13**	**2.35**	**2.98**	**2.91**	**2.89**	**3.22**	**2.50**	**3.24**	**3.85**

Figure 45 proves that SFHs have the highest values in general. Since 1990, all average transmission loss (Q_{Tc}) values for cooling have been lower than 4 kWh/m²a. The significant differences to the heating demand calculation can be mainly explained via the minor amount of cooling degree days (211, vs. > 3400). Moreover, the building element "ceiling to unconditioned attic" was assigned with the temperature correction factor *fc* = 0.



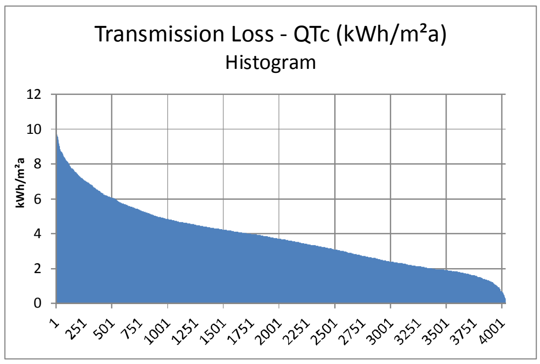


Figure 45: Average Transmission Loss ($\boldsymbol{Q_{Tc}}$) per Building Type and Construction Period

Figure 46: Histogram of the Transmission Loss ($\boldsymbol{Q_{Tc}}$) in case of Cooling

(source: City of Graz, 2013)

The histogram looks very similar to the heating demand process, with maximum values of the category "*Single Family House*" built before 1944.

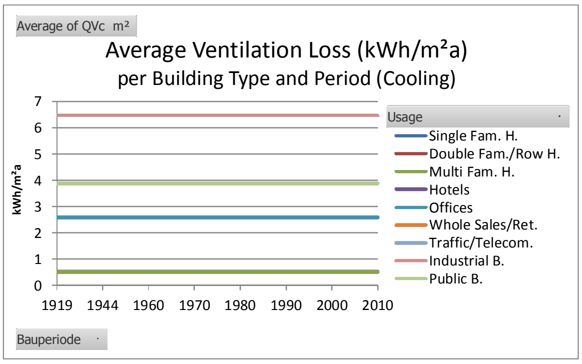
5.3.2. Ventilation Loss ($\boldsymbol{Q_{Vc}}$)

The results of the ventilation loss (Q_{Vc}) in kWh/m²a look quite different, as default values are used for air exchange rate per building type. The highest values per m² are assigned to the category "*Industrial Buildings*" (6.47 kWh/m²a) and "*Whole Sales and Retail*" (3.88 kWh/m²a). All residential buildings have an assigned ventilation loss of 0.52 kWh/m²a. These values do not change during the construction periods due to the applied method with the fixed air exchange rates by usage types.

Table 20: The Average Ventilation Loss ($\boldsymbol{Q_{Vc}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QVc m²	Column Labels									
Row Labels	Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	0.52	0.52	0.52	2.59	2.59	3.88	2.59	6.47	3.88	1.50
1944	0.52	0.52	0.52	2.59	2.59	3.88		6.47	3.88	0.89
1960	0.52	0.52	0.52	2.59	2.59	3.88	2.59	6.47	3.88	0.82
1970	0.52	0.52	0.52	2.59	2.59	3.88		6.47	3.88	0.73
1980	0.52	0.52	0.52	2.59	2.59	3.88	2.59	6.47	3.88	1.08
1990	0.52	0.52	0.52	2.59	2.59	3.88		6.47	3.88	1.06
2000	0.52	0.52	0.52	2.59	2.59	3.88		6.47	3.88	1.09
2010	0.52	0.52	0.52	2.59	2.59	3.88	2.59	6.47	3.88	1.01
Grand Total	**0.52**	**0.52**	**0.52**	**2.59**	**2.59**	**3.88**	**2.59**	**6.47**	**3.88**	**1.04**

Besides the value level, the histogram (*Figure 48*) visualizes another difference compared to the histogram of ventilation loss for heating (*Figure 38*). In this case, the amount of cooling degree days is constant (211), so only the four different classes for the default air exchange rate can be detected (cf. parameter settings, *A*).



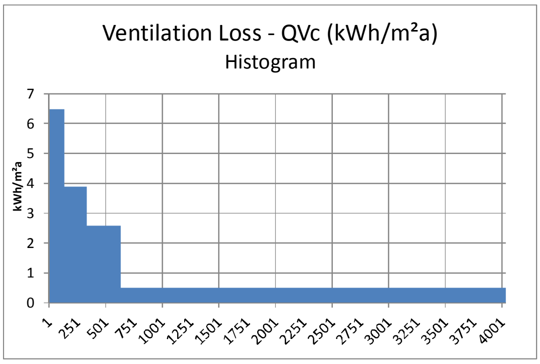


Figure 47: Average Transmission Loss ($\boldsymbol{Q_{Vc}}$) per Building Type and Construction Period

Figure 48: Histogram of the Transmission Loss ($\boldsymbol{Q_{Vc}}$) in case of Cooling

(source: City of Graz, 2013)

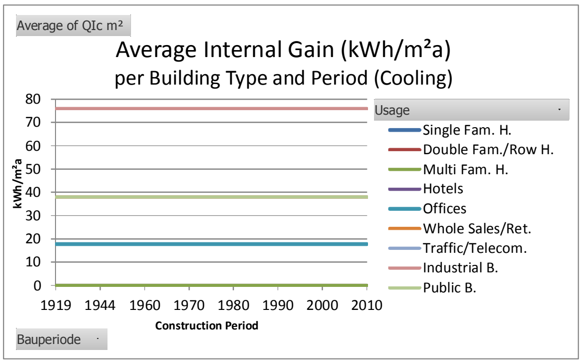
5.3.3. Internal Gain ($\boldsymbol{Q_{Ic}}$)

The output is based on the constant internal heat gain values in W/ m² (*qi*) and cooling days (34) for all buildings. Three categories of *qi* were considered, where the lowest refers to "*Offices*" and "*Traffic and Telecommunication*" with 3.5 W/m². For "*Industrial Buildings*", a value of 15 W/m² was assigned. All other building types were calculated with 7.5 W/m² and finally no value was used for residential buildings.

Hence, the summarized table only shows three different values per building type and construction period. As a conclusion, it can be determined that an amount of 34 cooling days with 15 W/m² of internal gain leads to about 76 kWh/m²a of annual internal heat gain. In comparison, about 38 kWh/m²a were obtained with 7.5 W/m², which is displayed in the following figures.

Table 21: Average Internal Gain (Q_{Ic}) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QIc m²	Column Labels									
Row Labels	**Single Fam. H.**	**Double Fam./Row H.**	**Multi Fam. H.**	**Hotels**	**Offices**	**Whole Sales/Ret.**	**Traffic/Telecom.**	**Industrial B.**	**Public B.**	**Grand Total**
1919	0.00	0.00	0.00	37.98	17.72	37.98	17.72	75.96	37.98	10.45
1944	0.00	0.00	0.00	37.98	17.72	37.98		75.96	37.98	4.35
1960	0.00	0.00	0.00	37.98	17.72	37.98	17.72	75.96	37.98	3.37
1970	0.00	0.00	0.00	37.98	17.72	37.98		75.96	37.98	2.60
1980	0.00	0.00	0.00	37.98	17.72	37.98	17.72	75.96	37.98	6.67
1990	0.00	0.00	0.00	37.98	17.72	37.98		75.96	37.98	6.55
2000	0.00	0.00	0.00	37.98	17.72	37.98		75.96	37.98	7.04
2010	0.00	0.00	0.00	37.98	17.72	37.98	17.72	75.96	37.98	5.90
Grand Total	**0.00**	**0.00**	**0.00**	**37.98**	**17.72**	**37.98**	**17.72**	**75.96**	**37.98**	**5.90**



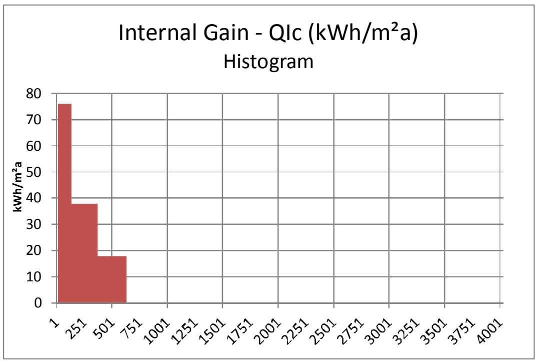


Figure 49: Average Internal Gain (Q_{Ic}) per Building Type and Construction Period

Figure 50: Histogram of the Internal Gain (Q_{Ic}) in case of Cooling

(source: City of Graz, 2013)

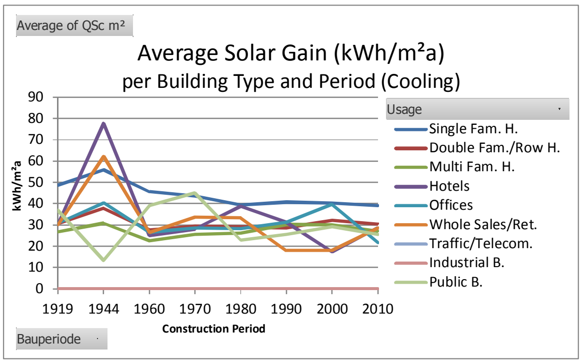
5.3.4. Solar Gain (Q_{Sc})

The methodology of solar gain is the same for heating and cooling, except for the solar irradiation values per month. This means that the applied SI values for the cooling season refer to the period from May to August only. The results for "*SFH*" (44 kWh/m²a) and "*Double Family or Row H.*" (30 kWh/m²a) look very similar to the heating season, in fact they are nearly the same. All other categories have higher values in the cooling season with an increase of about 6-9 kWh/m²a, compared to the heating season.

Generally, SFH has the highest values, which are decreasing since 1944. The lowest values are detected for MFH with an average of nearly 26 kWh/m²a. For "*Industrial Buildings*" no window area was assumed.

Table 22: The Average Solar Gain ($\boldsymbol{Q_{Sc}}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of QSc m² Row Labels	Column Labels Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	48.64	30.56	26.75	30.39	30.82	29.96	42.27	0.00	36.88	34.98
1944	55.93	37.73	30.86	77.77	40.41	62.20		0.00	13.36	51.01
1960	45.59	27.70	22.69	25.00	26.62	26.43	42.16	0.00	39.18	40.83
1970	43.59	29.42	25.49	28.11	28.65	33.72		0.00	44.93	40.41
1980	39.33	29.07	26.30	38.80	28.22	33.23	18.40	0.00	22.84	34.39
1990	40.72	28.73	30.17	31.25	31.21	17.97		0.00	25.52	35.56
2000	40.26	32.25	30.09	17.28	39.60	18.06		0.00	29.20	35.36
2010	39.07	30.47	27.12	28.75	21.85	28.56	15.01	0.00	25.59	34.48
Grand Total	**44.20**	**30.25**	**26.51**	**32.68**	**30.29**	**29.86**	**31.66**	**0.00**	**34.15**	**38.24**



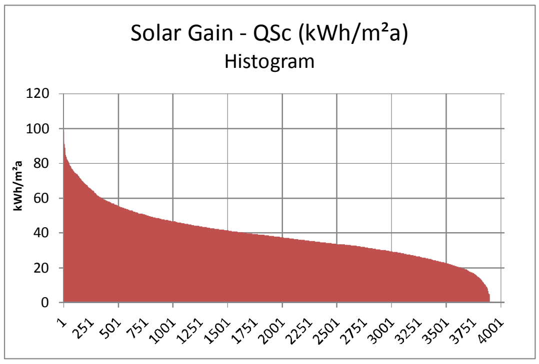


Figure 51: Average Solar Gain ($\boldsymbol{Q_{Sc}}$) per Building Type and Construction Period

Figure 52: Histogram of the Solar Gain ($\boldsymbol{Q_{Sc}}$) in case of Cooling

(source: City of Graz, 2013)

5.3.5. Specific Cooling Demand

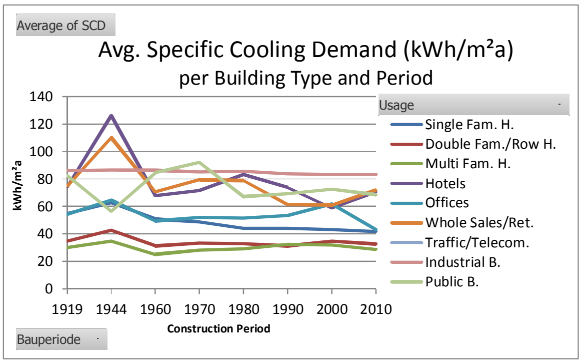
Table 23 displays the average specific cooling demand (SCD) in kWh/m²a, per building type and construction period. The highest average values were detected for "*Industrial Buildings*" (85 kWh/m²a), followed by "*Public Buildings*" (79 kWh/m²a) and "*Hotels*" (76 kWh/m²a). Generally, residential buildings have low values, the lowest refer to the category "*Multi Family House*" (29 kWh/m²a).

Table 23: The Average Specific Cooling Demand ($\boldsymbol{Q_c}$) in kWh/m²a per Building Type and Construction Period (source: City of Graz, 2013)

Average of SCD Row Labels	Column Labels Single Fam. H.	Double Fam./Row H.	Multi Fam. H.	Hotels	Offices	Whole Sales/Ret.	Traffic/Telecom.	Industrial B.	Public B.	Grand Total
1919	54.84	34.77	29.93	74.26	54.24	74.84	67.26	85.98	82.50	50.85
1944	62.88	42.73	34.71	126.23	64.79	110.07		86.32	56.62	62.23
1960	50.87	31.27	25.22	67.74	49.45	70.72	67.01	86.30	84.53	49.33
1970	48.85	33.28	28.27	71.59	51.83	79.35		85.19	91.98	48.17
1980	44.25	32.92	29.32	83.42	51.44	78.75	41.04	85.55	67.19	46.13
1990	44.11	31.35	32.47	73.68	53.43	61.16		83.84	69.05	45.70
2000	43.14	34.70	32.12	58.82	61.91	61.07		83.25	72.53	45.60
2010	41.65	32.64	28.87	70.58	43.14	71.82	36.10	83.33	68.60	43.23
Grand Total	**49.10**	**33.91**	**29.37**	**76.23**	**53.51**	**74.61**	**55.19**	**84.93**	**79.26**	**49.02**

Figure 53 visualizes these average values (SCD) per building type and construction period. It can be noted that industrial buildings have the highest heat demand in general, with an increase during the construction period until 1960. Public buildings show the highest average SCD until

the end of the sixties. For all other building types, SCD starts to decrease constantly from the period of 1944.



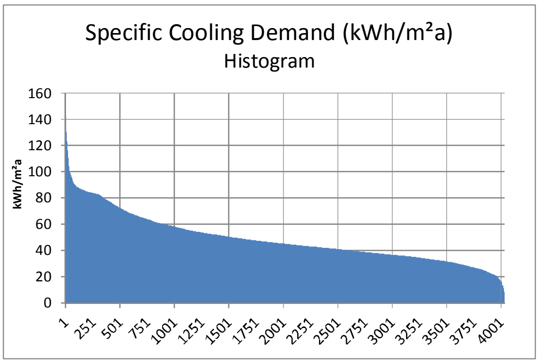


Figure 53: Average Specific Cooling Demand (SCD) *per Building Type and Construction Period*

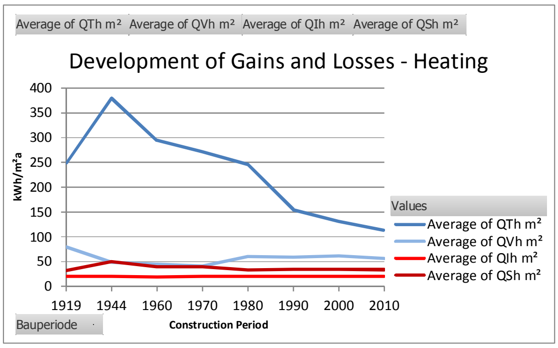
Figure 54: Histogram of the Specific Cooling Demand

(source: City of Graz, 2013)

Figure 54 shows the histogram of all used datasets, arranged by SCD in descending order. All "Top" values refer to "*Hotels*", “*Whole Sales and Retail*” and “*Public Buildings*”, in general low level results were obtained for “*Multi Family Houses*” and “*Double Family House/Row H.*”. Most of the SCD values (2271) are between 40 and 80 kWh/m²a. At the right side of the histogram low SCD values are displayed, which mainly refer to “*Multi Family Houses*”. A consistent development can be noticed for the category “*Industrial Buildings*”.

5.4. Summary – Individual Results

Concluding this section, the individual results show that the highest value are represented by the heat transmission losses (Q_{Th}) with a constant decrease since 1944. In case of cooling, solar gains (Q_{Sh}) affects the most on the annual demand.



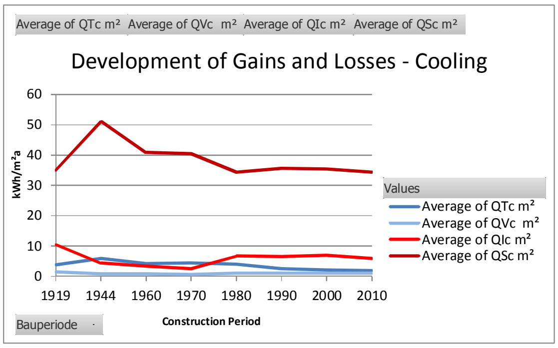


Figure 55: Development of Gains and Losses in case of Heating

Figure 56: Development of Gains and Losses in case of Cooling

(source: City of Graz, 2013)

The development in case of cooling looks similar, but with the highest values for solar gains (Q_{Sc}). Ventilation (Q_{Vc}) and transmission Losses (Q_{Tc}) seem to play a minor role, not to forget that all gains have to be treated as losses for the cooling.

In the following chapter the final results, by means of specific and total demand, will be presented for the districts of *Liebenau* and *Inner City*. Both the heating and cooling demand are presented.

5.5. Heating Demand – Inner City District

The specific heating demand (SHD) on the left side of *Figure 57* was calculated as follows: the total annual heating demand divided by the total energy reference area (AR) of the buildings per cell. The range varies from 71.52 kWh/m²a to more than 800 kWh/m²a. High value pixels can be detected on the east side of the district, adjacent to the "*Stadtpark*". Occasionally higher values are placed at the "*Schloßberg*" area, around the area of "*Jakominiplatz*" and on the west end of the "*Murgasse*", near the "*Erzherzog-Johann*" bridge.

The total amount of the annual heating demand (on the right) displays a slightly different view. Previously unremarkable pixels of the center now belong to the 5th class with an annual demand between 5 and 10 GWh/a. These hotspots in the center of the district represent the old city center of Graz showing the rather high density in those areas. The area around "*Stadtpark*" has a rather insignificant heating demand, while the areas of "*Karmeliterplatz*" and the Styrian government are contiguous to the "*Burgtor*".

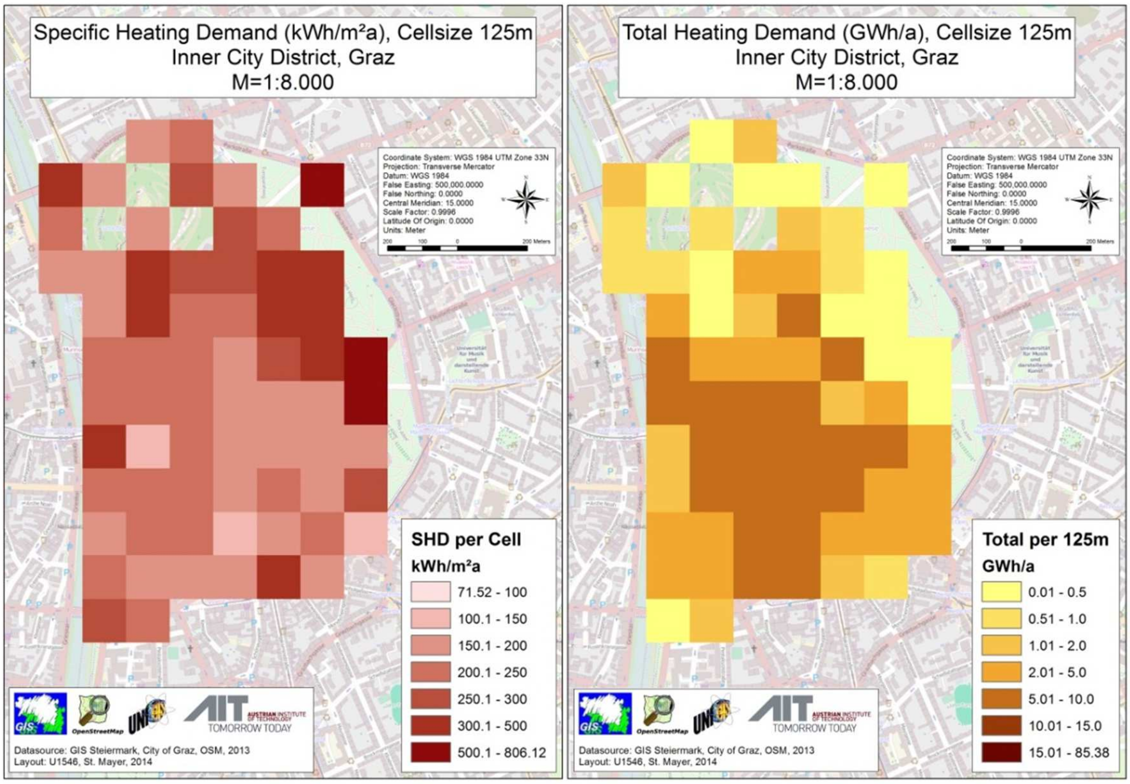


Figure 57: Specific and Total Heating Demand of the Inner City District

5.6. Heating Demand – Liebenau District

Considering the Liebenau district, the distribution of the specific heating demand (SHD) is partly inhomogeneous, not only because of the bigger size of the area compared to the *Inner City*. In order to make the results comparable for both districts, the classification range is the same as applied for the *Inner City*.

The building structure is different in the northern part of *Liebenau*, due to a mixture of industrial, public and residential buildings. This is reflected in the higher SHD values. Again, the south west of the district looks very homogenous due to an accumulation of SFH, with generally low average values. The highest values can be found in the western part of the district, where single industrial buildings are located. In the southern area, higher values refer to an industrial cluster.

The visualization of the thermal demand hotspots is more conspicuous within the *Liebenau* district. The southern part, described as industrial cluster, seems to be the highest heating demand area in *Liebenau* with a maximum value of up to 85 GWh/a. Additionally, hotspot areas are detected around "*Murpark*" (top three value with 30.8 GWh/a) and the "*Allianz Arena*".

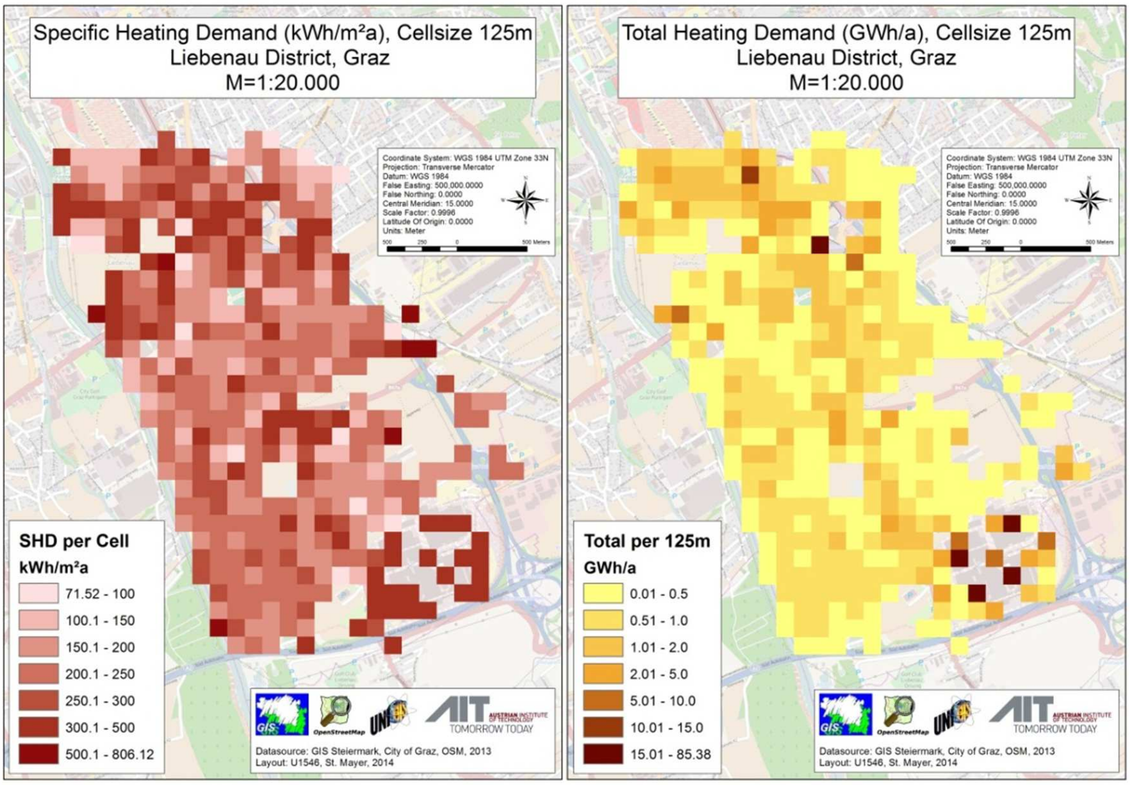


Figure 58: Specific and Total Heating Demand of the Liebenau District

5.7. Cooling Demand – Inner City District

Based on the calculation method, all cooling demand results are very similar to the heating demand results, except for the lower value range. Therefore, the detection of high value pixels in both districts is likewise the heating demand. For the specific cooling demand (SCD) this range is between 19.55 kWh/m²a and 128 kWh/m²a. The highest SCD result per 125m cell is located adjacent to the "*Stadtpark*", at the "*Schloßberg*" area, around the "*Jakominiplatz*" and at the west end of the "*Murgasse*".

The main hotspot for the annual cooling demand is situated in the south center of the *Inner City* with values between 0.5 and 1.0 GWh/a. The northern regions of the district and the areas around the "*Stadtpark*" display lower results.

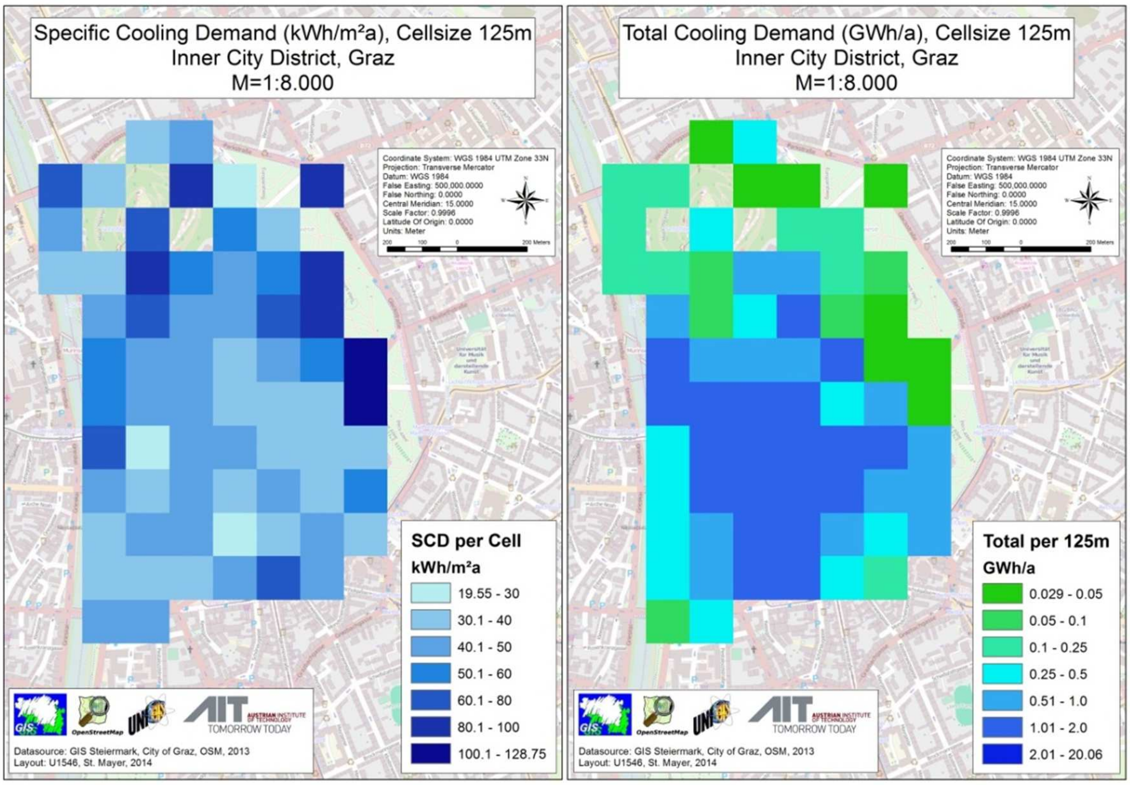


Figure 59: Specific and Total Cooling Demand of the Inner City District

5.8. Cooling Demand – Liebenau District

Likewise to the heating demand of *Liebenau*, the spatial distribution of the specific cooling demand (SCD) in *Liebenau* is different in the northern part, but with generally higher SCD values based on the mentioned mixture of building types. Again, the south west of the district is very homogenous with low level SCD values. The highest values have been noticed in the western and southern parts of the district, where single industrial buildings and an industrial cluster is located.

The southern industrial cluster has a maximum value of more than 20 GWh/a, which approves this region as the areas with the highest energy demand (cooling) of the whole investigation area. The other hotspots can be found once more (according to the SHD) around "*Murpark*" and the "*Allianz Arena*".

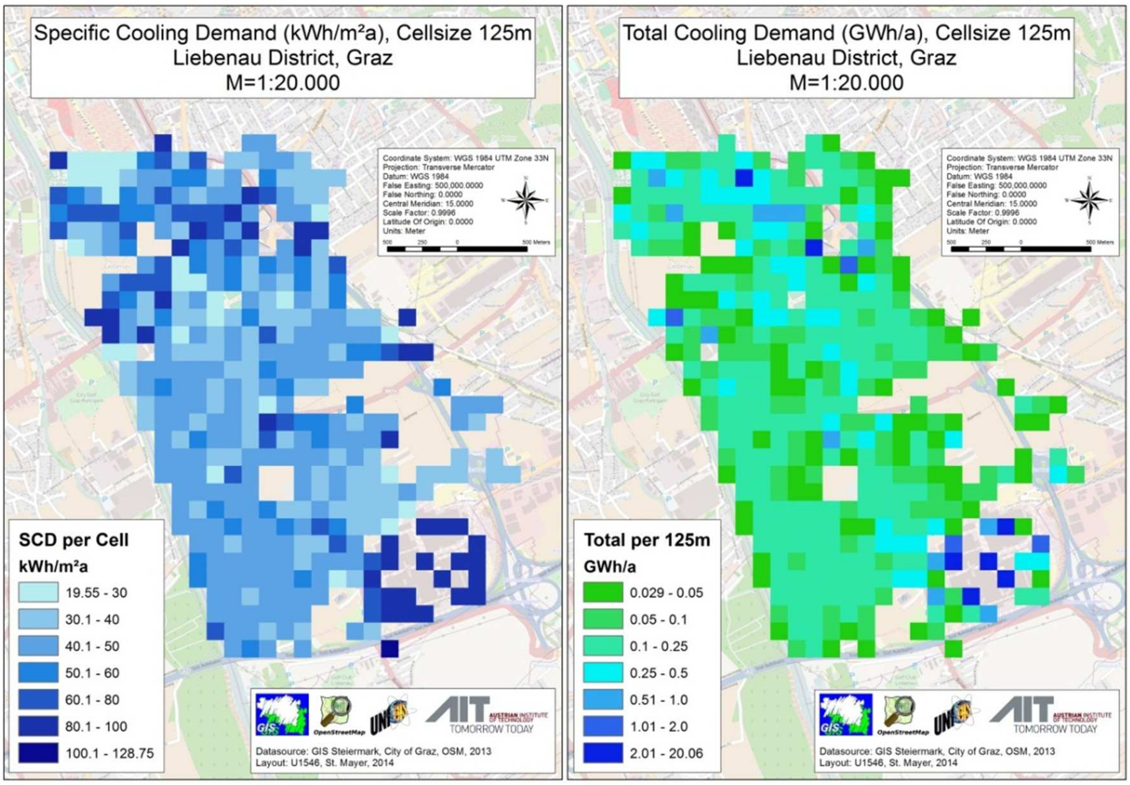


Figure 60: Specific and Total Cooling Demand of the Liebenau District

5.9. Achievement of Objectives

This section will answer the questions prompted in the beginning (cf. chapter *1.2* "*Objectives*").

What is the spatial distribution of the thermal demand for residential and non-residential buildings within city quarters and what are the main differences between these diverse usage types?

The results (specific heating/cooling demand) display that areas in the *Liebenau* district with non-residential buildings generally tend to a higher thermal demand per 125m raster. This effect is not obvious for the *Inner City* district, but could be explained via the old building structure of the city center, where public and residential buildings are more mixed up as well. Yet, some high value cells (SHD/SCD) exist in *Inner City* areas, especially those with a small amount of non-residential buildings per pixel.

The visualization of the total thermal demand in GWh/a underlies this first impression. Inside the *Liebenau* district, residential areas can be detected within the class from 0.5 to 1.0 GWh/a. The value per pixel increases with the amount of non-residential buildings. Thus, the main difference can be explained via the compact building structure and the different appearance of building types in the *Inner City* district, against a rather more structured situation in *Liebenau* with some industrial and public building clusters.

Is it possible to identify thermal hotspots in the specified area?

The visualization of the total heating demand (GWh/a) per Cell allows to detect hotspots in both districts. Depending on the input data, requirements and the classification intervals, proper information is available. For the applied layout (total demand results) the value density within high classes is very low (cf. chapter 6, "*Discussion*"), which means that only a view "hotspot" values will be detected with this approach. Hotspots mainly refer to industrial and public building cluster, but also to the old city center of Graz, due to the high density of residential building (MFH). This outcome is valid both for the heating and cooling demand.

Is it possible to spot the mostly affected energy-consuming building types? When were those buildings constructed?

Figure 43 gives an overview about the average specific heating demand per building type and period of construction. It is evident that there is a coherent decrease in thermal demand, referring to the construction period and that the highest values per building type were not found before 1919, but between 1919 and 1944. Of course, due to the calculation method, higher values were obtained for non-residential buildings. The maximum outcome (> 600 kWh/m²a) was detected for "*Industrial Buildings*" between 1944 and 1960. Furthermore, high values were obtained for "*Public Buildings*" (517 kWh/m²a, between 1960 and 1970) and the category "*Whole Sales and Retail*" (529 kWh/m²a, between 1919 and 1944).

Considering residential buildings, MFH obtain the lowest energy demand results of all building types, what is reflected in the calculation approach due to the characteristic length. The maximum value of 204 kWh/m² was detected between 1919 and 1944. In the last construction period (2010) the energy demand was about 65 kWh/m²a only. Considering all residential building types, the highest outcome was obtained for SFH between 1919 and 1944 with an average of 364 kWh/m²a. It can be determined that the building period between 1919 and 1944 yields the most energy-consuming buildings, reflected also by the U-values used in the calculation.

Does the chosen model provide a scalable and transferable picture of relevant information to perform realistic energy demand scenarios for residential buildings?

The results of the thermal demand calculation processes seem to picture out realistic values. Nevertheless, areas with a lower building density have to be questioned carefully. It also has to be considered that the amount of assigned buildings per building type is not homogeneous, even with different construction periods. The best results were obtained for residential buildings, as the amount of datasets has been sufficient for this study. This will be confirmed in chapter "*Discussion*" subsequently.

How can relevant influences and parameters be ideally linked to obtain a quantitative evaluation of the thermal demand?

As no data was available from energy supplier or metering companies, standardized values for residential buildings (cf. AEA, 2011) are used to compare with the average results per building type and construction period. Additionally, SHD values will be linked to construction period and a specified range of characteristic length values, in order to confirm the connection between building geometry and construction period. The results of this comparison will be related to standardized values based upon the Austrian building regulations.

Which input parameters are mandatory and are they sufficiently available?

In order to calculate geometrical building properties, mandatory building data at least consists of the footprint area and the building height. Very occasionally missing buildings do not harm the overall calculation results, but should be limited. The number of floors can simplify the calculation method, but can also be derived from the building height. This was necessary for some buildings, due to a mismatch of building height and number of storeys.

To perform a significant and comparative building study, building properties like age and occupancy/usage are important. Going into detail would also require information about the used heating system and source or air conditioning, but was not planned in the course of this approach.

Climatic information about temperature and solar irradiation is essential for the individual calculations both of gains and losses. The simplified and in this work applied method works with degree days as well as heating and cooling days per year. The solar irradiation has to be available per month with a specified orientation (cardinal points) and inclination (simplified with 90° for every building).

6. DISCUSSION

Due to a lack of data availability, it has not been possible to compare the results with real consumption data from energy supplier or metering companies. Hence, this chapter deals with the analysis of the results, in order to evaluate and confirm their plausibility. The focus will be placed on the heating demand only, as the cooling demand is similar but has a lower range of values. As far as non-residential building types are concerned, it has to be mentioned that the available sample size is not really significant.

6.1. Evaluation - Specific Heating Demand

The following figures show a "*QQ-Plot*" distribution for residential (left figure) and non-residential buildings (right figure). Quantiles of the individual specific heating demand values (vertical axis) are compared with quantiles of the standard deviation (σ) on the horizontal axis. The more the values are offset from the center ("*Standard Normal Value*"), the higher the amount of variation. As the points are following a non-linear pattern, it is displayed that the data is not distributed as a standard normal.

The kurtosis of both point curves signifies that lower and higher values have a stronger offset from the model diagonal, which implies a lower value density. This also includes that the distribution of residential buildings is more homogenous than for non-residential buildings. A kurtosis parameter of about 3.3 for non-residential buildings and 3.1 for residential buildings confirms this distribution (ArcGIS: < 3, high distribution).

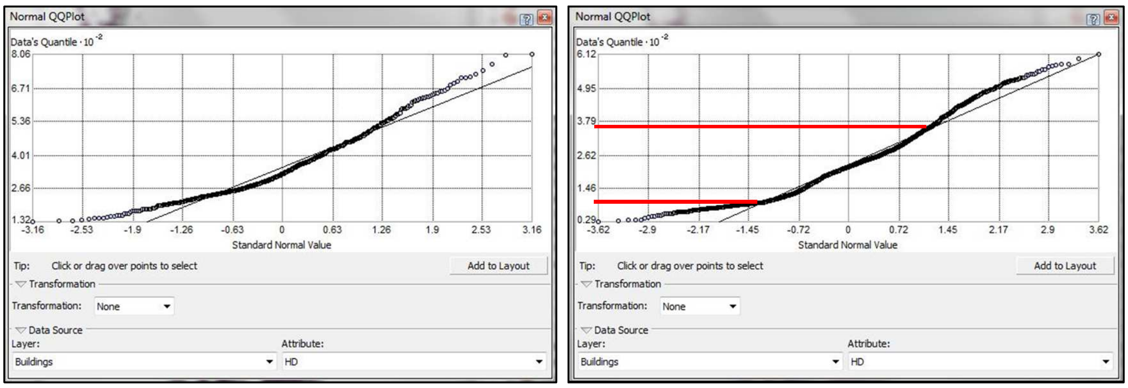


Figure 61: QQ-Plot Diagram (SHD, Standard Deviation) of Non-Residential (l.) and Residential buildings (r.)

Both histograms below (SHD - horizontal axis) display the amount of values per range. They confirm a lower density for small and higher sector values. For non-residential buildings (632) the skewness factor is about 0.84, which signifies that most of the values occur on the left side of the diagram (right skewness), just between 200 kWh/m²a and 460 kWh/m²a. The mean value for non-residential buildings is 350.6 kWh/m²a.

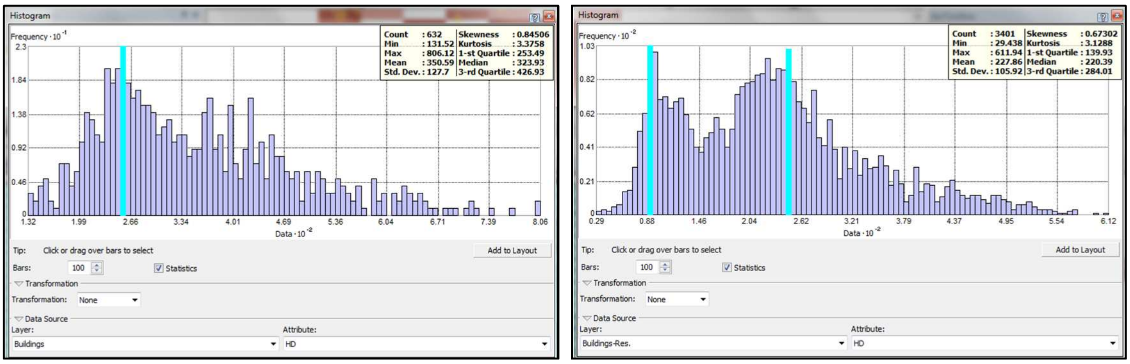


Figure 62: Histogram (SHD) of Non-Residential (l.) and Residential Buildings (r.)

For the amount of residential buildings (3401), a skewness factor of 0.67 is displayed. This means that more of the values are distributed near the centre, as zero would imply a *Gaussian* distribution. Absolute values on the horizontal axis show a significantly higher SHD range for non-residential buildings, going from 131.5 kWh/m²a to 806.1 kWh/m²a, compared to residential buildings with values between 29.4 kWh/m²a and 611.9 kWh/m²a. A standard value from the Austrian Building typology assigns a maximum value (273.5 kWh/m²a) to a SFH constructed before 1919 (cf. AEA, 2011). This difference seems exceptionally high, but the histogram (see *Figure 62*) clarifies that the value range for residential buildings is quite comprehensive.

From the entire right side of the histogram for residential buildings, 11 out of 607 values can be assigned to "*Double Family or Row House*". The others belong to SFH with a maximum construction period of 1980. The two peaks on the left side mainly refer to different construction periods as well, where the low value peak includes buildings mainly constructed after 1990. **The major amount of SHD values for residential buildings ranges between 76 kWh/m²a and 300 kWh/m²a, with a total mean value of 227 kWh/m²a**.

6.2. Validation - Specific Heating Demand

Initially, it was planned to compare the results with Austrian standard values from the "*Tabula-Brochure*" (AEA, 2011), which is a summary of different building types (SFH, DFH, MFH, ...) and ages. Amongst others, based on information from the Austrian building and dwelling register, this typology contains 28 model buildings, characterizing the Austrian residential building stock. It covers building characteristics and energy-relevant properties. Nevertheless, due to the wide range of values mentioned above, it is rather difficult to compare them with the suggested individual standard values, especially as there is no reference to the geometrical property of a building.

Thus, an alternative methodology, mentioned in the ÖNORM B8110-1 (ASI, 2011a), will be used to validate the results. In consideration of building geometry and the local climatic situation, parameters like heating demand per energy reference area and the characteristic length (cf. chapter *4.4.1.3*) of a building have to be used for the declaration of thermal insulation.

The figure "*Development of the Heating Demand in Austria*", presented in ÖNORM B 8110-1 (ASI, 2011a), illustrates the development of the heating demand per construction period, referring to standard characteristic length values. All values ("*Heizwärmebedarf*", l_c) are based on the assumption of two vertical and two horizontal building elements with a window fraction of 20%. A significant decrease of the heating demand can be noticed, irrespective of increasing characteristic length and building period.

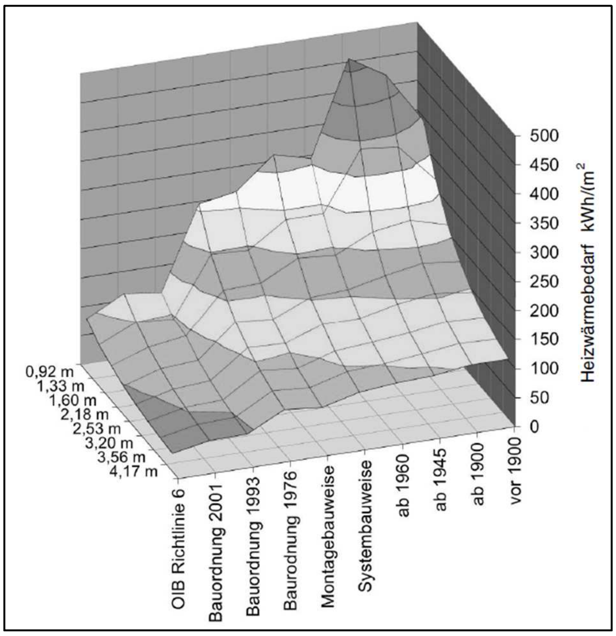


Figure 63: Development of the Heating Demand in Austria" (ASI, 2011a)

Finally, the equivalent figure will be presented for the calculated results in this thesis, in order to identify potential relations or similar characteristics. For the calculation of the characteristic length, all external building elements were used. In comparison with the method mentioned above (with two vertical building elements), this calculation used the modelled outdoor area of each building, certainly including ceilings of unconditioned attics and basements.

The following table includes all residential buildings (*SHD*, l_c), as they are more homogenous and comprehensive than non-residential buildings. All values were derived via SQL query with a group on construction period, average SHD and l_c values within the applied range. Due to a lack of data, some values (red) were calculated from the average of the adjacent construction periods. For the same reason, other characteristic length (l_c) intervals were used in the original diagram (*Figure 63*).

Table 24: Progress of the Specific Heating Demand of Residential Buildings

Construction Period/Lc	< 1919	1919 to 1944	1945 to 1960	1961 to 1970	1971 to 1980	1981 to 1990	1991 to 2000	2001 to 2010
0.92 m	378.67	388.41	421.34	386.21	347.34	227.36	178.47	116.24
1.12 m	284.58	300.56	285.99	261.76	251.73	151.01	124.85	98.12
1.25 m	240.53	239.59	252.42	235.77	225.01	131.62	108.04	90.06
1.50 m	204.30	194.09	213.36	205.76	200.40	120.26	97.44	79.43
1.75 m	176.31	172.31	180.82	168.23	167.06	99.69	84.81	69.46
2.0m	155.98	162.82	152.38	156.80	150.22	91.92	77.11	56.96
2.5 m	127.09	124.08	121.07	118.12	121.05	77.19	63.43	49.67
> 3 m	79.38	84.51	89.65	91.63	97.67	58.11	46.38	34.64

The own figure of the "*Development of the Specific Heating Demand*" looks quite similar. It has to be considered that the scale of the characteristic length axis is not the same and that the building periods differ from the original figure. Yet, there is an appropriate and significant development of the SHD within the different building periods as well as of the ranges of the l_c.

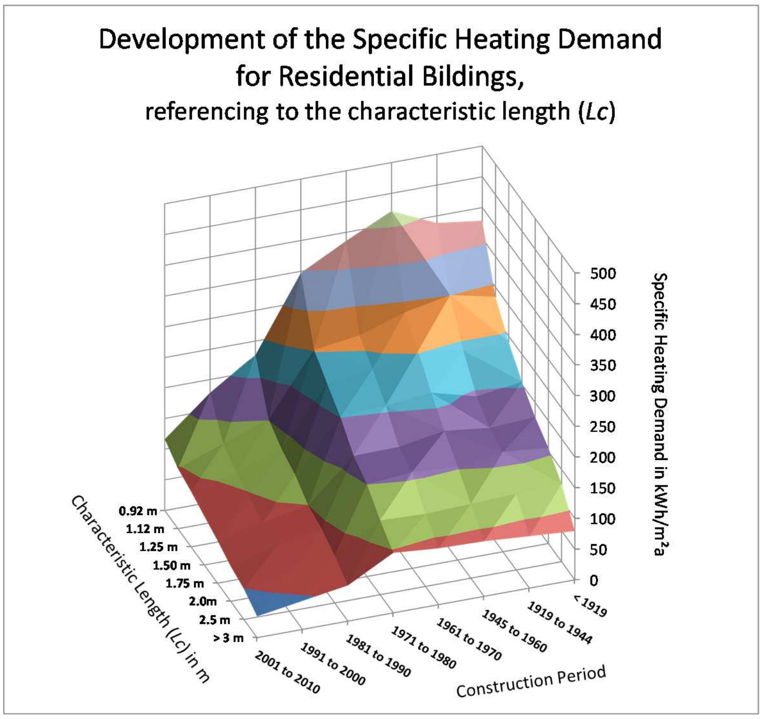


Figure 64: Development of the Specific Heating Demand of Residential Buildings (own results)

The highest values with a maximum characteristic length of 0.92 m have been noticed during the period of 1945 -1960. This degradation in parts from previous periods and a continuous high level phase can be explained both due to the bad economic situation and missing construction regulations in Austria. In the *Liebenau* district in particular, most of the residential buildings were constructed between 1945 and 1980, as already visualized in *Figure 34* (cf. chapter *5.1*). A remarkable and broad decrease in terms of heating demand was visualized between the periods of 1980 and 1990, which can be interpreted as an effect on the implementation of the Austrian construction regulation (respectively in Styria in1983).

The applied approach provides a quick methodology to predict the thermal demand patterns for city quarters. It delivers adequate information about the thermal demand patterns within the area of investigation. Depending on construction period and building geometry, the range of the specific heating demand strongly varies both for residential and non-residential buildings. Concerning residential buildings and with the proven relation to construction period and building geometry, the results for the thermal demand seem to be rather high but reasonable. Nevertheless, they reflect the effects of the Austrian building regulation, especially after its implementation in Styria in the year 1983.

7. CONCLUSION

7.1. Summary

Modern cities are under a constant pressure to meet the enormous energy requirements. A majority of this energy is consumed by the private and public sector buildings. Information about the thermal demand patterns within cities could, among other things, contribute to an optimization of energy supply chains or a reduction of energy losses during transport as well as transport costs. Therefore, the aim of this paper is the modeling of the heating and cooling demand for buildings of a city, in order to gather the demand patterns within different parts of the city and to localise hot spots of demand. Two districts of Graz with a different building and population structure have been chosen as the study area.

At the beginning of the main part of the thesis, the demand calculation is presented. It mainly deals with the energy balance of individual buildings. The practical implementation of this method is started with the creation of a building model, which has to contain all the relevant geometric and climatic parameters. Subsequently, individual demand calculations for heating and cooling, divided into gains and losses, are described. The chapter „*Results*" contains all partial results for the heating and cooling demand, as well as the initially required answers to the research questions. These include the specific heating and cooling demand according to building age and type, the average specific need per year as well as the total annual need within a 125 m raster. In the chapter "*Discussion*", the individual results are examined according to their severity and plausibility. The conclusive validation, using the example of the specific heating demand, shows the relation between building age, geometry as well as heating demand and opposes their characteristic attributes against standardised values.

This master thesis shows in detail which kind of influences have to be regarded when determining the heating and cooling demand of buildings. Thus, on the one hand, qualitative and quantitative statements could be made about the building quality and the demand patterns, on the other hand, the interaction of building geometry, age and type is demonstrated. What is more, the significant influence of climatic conditions is clearly highlighted.

There is enough potential for an optimization of the calculation method as well as the level of detail of the building model for subsequent papers. The involvement of different heating systems and their impact on the final energy would be very interesting extensions of this issue.

7.2. Personal Review

The topic of this master thesis was specified in the course of a public tender by the Austrian Institute of Technology (AIT). At the beginning, the term "Energy in Cities" was the cornerstone and the initial aim was to model the heating and cooling demand for a certain study area. The city of Vienna should be compared with a second city, also with the argument that the developed methodology will be applicable to both individual cities and different city quarters. Primarily, attention was paid to literature on similar studies and especially on their selection concerning data sources. Hence, the Austrian building and dwelling register has proven to be the comprehensive and uniform data source, which is also mentioned in various approaches. But the problem was that data from municipalities and cities was not easily available, although decidedly noted in the laws to the GWR that it may be used for research purposes. Finally, the corresponding data out of the GWR was kindly provided by the city of Graz.

While finding a proper methodology, it became apparent that the determination of the heating and cooling demand of buildings must be carried out exclusively via the calculation of the heat balance of individual buildings. Therefore, the monthly balance method described in ÖNORM B 8110-6 was modified and simplified by use of heating degree days, in order to determine the annual heating and cooling demand. For the practical implementation of the method, a building model had to be generated with the required information. Data out of the GWR was combined with the building polygons, in order to have the geometrical characteristics of the buildings available with the energetically and climatically relevant parameters. Along with it, it was necessary to determine the real external surfaces of the individual buildings and their share of cardinal points.

The proper demand calculation was performed with the Python programming language and integration as a menu in the ArcToolbox. Thermal gains and losses of buildings can also be calculated separately and as a combination of both. Relevant parameters and default values, such as U-values of building elements, can (e.g. depending on building age or type) be modified, either in the menu window of the ArcToolbox (parameters) or directly in the Python scripts (default values). The final analysis of the results has shown that despite all the problems and difficulties, good and reasonable results could be obtained.

In retrospect, it can be noted that the applied method doesn´t require implicit access to the GWR. Assuming the age of the building and its occupancy are known, building footprint and building height are sufficient to model the heating and cooling demand. Another point is that the data consistency of the GWR must be closely examined. There were a whole series of error sources and types discovered. Their removal has taken quite a long time and it cannot be ruled out that other error sources are present.

7.3. Conclusion and Outlook

Apart from data acquisition and various data inconsistency issues, the applied method delivers significant and adequate information about the thermal demand patterns within an area of investigation. The range of values strongly varies depending on construction period and building geometry, both for residential and non-residential buildings. It has to be considered that the amount of non-residential buildings is too low to obtain significant results. Concerning residential buildings, the results for thermal demand seem to be slightly high but reasonable, with the proven relation to construction period and building geometry. Additionally, they reflect the effects of the Austrian building regulation, especially after the implementation in Styria in the year 1983.

It can be summarized that the specific heating demand mainly depends on geometrical properties, which are represented through the characteristic length (l_c), and the construction period, which has an effect on the heating insulation of buildings. Additionally, climatic factors have to be considered, especially heating degree days and solar irradiation. Referring to the applied methodology, there is still potential for optimization. The current method calculates all geometrical building properties based on building footprint and building height. An application of the „extrusion-method", as described by LEDOUX (2011), would help to generate a topologically consistent 3D model. What is more, an inclusion of roof areas and their orientation could increase the quality of the building model as well.

This entire approach focused on the heating and cooling demand on the level of usable energy, which is described as the amount of energy necessary to preserve the desired room temperature for a conditioned building. Consequently, with the applied method, a rather quick prediction of the thermal demand patterns for city quarters or entire cities is possible, also for other Austrian cities. But, it has to be stated that the current master thesis did not consider heating systems, which are necessary to determine the final energy demand for a building (cf. ASI, 2007). The difference between thermal demand and real consumption data can be up to 80%, depending on the heating system, energy carrier or occupancy (e.g. hot water), due to storage, allocation and provision losses.

Furthermore, in case of refurbishment actions to be taken by the city, it is not only important to know where demand hotspots are located, but also why so much demand is required. Hence, for subsequent papers it would be interesting to extend the calculation method concerning heating systems. So they can determine the influence of different heating systems or energy carrier on the total energy demand. This would allow an estimation of the final energy demand of buildings, by the usage of the energy expenditure measures (dependent on characteristic length (l_c) and energy carrier), mentioned by the OIB (2011). Based on the final energy demand of buildings, primary energy demand and CO_2-factors could be derived, which demonstrates the comprehensive scope for future steps. The next level would be a comparison between calculated values and real consumption data.

The main benefit of the presented approach lies in the possibility to quickly obtain information about the spatial demand patterns for a case study, with only a low amount of input data.

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9. APPENDIX

a) Transfer Loss – Calculation:

Table of U-values applied per building type, age and element. Except for SFH, all building types are treated like MFH.

Construction Period	Building Type	KD	OD	AW	FE
<= 1944	SFH	1.20	1.0	2.00	2.50
<= 1944	MFH	1.20	1.0	1.50	2.50
<= 1960	SFH	1.95	1.35	1.75	2.50
<= 1960	MFH	1.10	1.35	1.30	2.50
<= 1980	SFH	1.35	0.55	1.20	3.00
<= 1980	MFH	1.35	0.55	1.20	3.00
<= 1990	SFH	0.60	0.30	0.70	2.50
<= 1990	MFH	0.60	0.30	0.70	2.50
<= 2000	SFH	0.45	0.30	0.50	2.50
<= 2000	MFH	0.45	0.30	0.50	2.50
> 2000	SFH	0.40	0.20	0.40	1.90
> 2000	MFH	0.40	0.20	0.50	1.90
					(cf. OIB Leitfaden, 2011)

b) Ventilation Loss, Internal and Solar Gain Calculation:

Calculation parameters and used default-values per building type.

ID	BUILDING TYPE	Ventilation nl (1/h)	Internal Heat Gain qi h,c (W/m²)		Shading Reduction Factor Fs h, c	
1	Single Family House	0.4 (FI)	3.75	-	0.85	1
2	Double Family or Row Hause	0.4 (FI)	3.75	-	0.85	1
3	Multi Family House	0.4 (FI)	3.75	-	0.75	1
4	Hotels	2 (RLT)	7.5	7.5	0.75	1
5	Offices	2 (RLT)	3.75	3.75	0.75	1
6	Whole Sales and Retailing	3 (RLT)	3.75	7.5	0.75	1
7	Traffic and Telecommunication	2 (RLT)	3.75	3.75	0.75	1
8	Industrial Buildings and Storage Rooms	5 (RLT)	7.5	15	0*	0*
9	Public buildings	3 (RLT)	3.75	7.5	0.75	1
						(cf. ASI, 2011b)
						*(no windows assumed)

c) Solar Gain Calculation – Applied Solar Irradiance per Moth and Orientation:

ID	January	February	March	April	May	June	July	August	September	October	November	December
N	13.11	21.08	28.36	39.48	55.21	58.99	59.41	44.32	35.63	23.81	13.21	9.6
NNW_ NNE	13.11	21.08	30.23	43.71	61.53	65.39	66.64	50.03	37.86	23.81	13.21	9.6
NW_NE	13.78	22.62	35.03	50.76	70.16	74.12	75.87	59.9	43.3	26.87	13.92	9.94
WNW_ENE	15.72	26.16	42.43	59.22	79.55	82.66	85.31	71.33	51.09	32.66	16.01	11.36
W_E	19.51	32.14	52.12	67.68	88.18	88.48	93.14	81.71	60.37	40.86	20.14	14.63
WSW_ESE	25.66	40.81	60.88	73.61	91.63	89.06	94.34	87.43	68.16	50.27	26.63	20.66
SW_SE	31.95	49.49	68.8	77.27	91.63	86.15	91.93	89.68	74.97	59.04	33.35	26.91
SSW_SSE	37.06	56.49	74.95	78.96	89.71	81.69	87.32	89.33	79.92	66.04	38.9	31.97
S	39.63	60.16	78.39	78.96	87.41	77.61	81.9	87.25	82.14	70.14	41.85	34.39
												(cf. ASI, 2011b)

d) Applied Python scripts:

```
###############################################################################
# Name: script1_QT_v2.py
# Author: Stefan M. (U1546)
#
# Description:
# Adds variable U-Values (based on OIB 2011), depending on building type and age,
# to different building elements (AW, KD, OD, FE) and calculates the Heat
# Transfer Coefficient (LT) for heating and cooling.
#
# Requirements:
# Building polygons (feature Class or shapeFile, Building properties (year of
# construction or renovation, building type), geom. building features and HDD.
#
# Parameters:
# f(i,h,c)... Temperature Correction Factor
# Ui ... Heat Transfer Coefficient (W/m²K)
# Ai ... Surface Area (Building Envelope, AW_real) m²
#
# Output:
# The final output is the overall Transmisssion Heat Loss (QT) per building.
# other Parameters:
# temp. correction factor per building element, HDD, CCD and conversion factor
###############################################################################

# Import system modules
import arcpy
import sys
import string
import os
from arcpy import env

# Set environment settings
env.workspace = "C:\UniGIS\1 Master Thesis\3_Datasource\7_Projects\FinalDB.gdb"
arcpy.env.overwriteOutput = True

try:
    Inpath = arcpy.GetParameterAsText(0)
    Usage = arcpy.GetParameterAsText(1) # Usage(single or multi family house, public buildings, industrial b., ...)
    Age = arcpy.GetParameterAsText(2)   # year of construction or renovation

    AW_f = arcpy.GetParameterAsText(3)  # temperature correction factor (AW)
    KD_f = arcpy.GetParameterAsText(4)  # temperature correction factor (KW)
    OD_f = arcpy.GetParameterAsText(5)  # temperature correction factor (OW)
    cf = arcpy.GetParameterAsText(6)    # conversion factor (0.024)

    HDD = arcpy.GetParameterAsText(7)   # HDD per building
    CDD = arcpy.GetParameterAsText(8)   # HDD per building

# Variables
    a = float(AW_f)
    b = float(KD_f)
    c = float(OD_f)
    g = float(cf)

# Add Fields for U-values and Calc. Results
    arcpy.AddField_management(Inpath,"U_KD","DOUBLE")
    arcpy.AddField_management(Inpath,"U_OD","DOUBLE")
    arcpy.AddField_management(Inpath,"U_AW","DOUBLE")
    arcpy.AddField_management(Inpath,"U_FE","DOUBLE")
# Add Fields for Heat Transfer Coefficient
    arcpy.AddField_management(Inpath,"LTh","DOUBLE")
    arcpy.AddField_management(Inpath,"LTc","DOUBLE")
# and Results for total Transfer Loss (Qh,c)
    arcpy.AddField_management(Inpath,"QTh","DOUBLE")
    arcpy.AddField_management(Inpath,"QTc","DOUBLE")
    arcpy.AddField_management(Inpath,"QT","DOUBLE")

# Update U-Values for buildings and calc. QT:
    rows = arcpy.UpdateCursor(Inpath)
    for row in rows:
        d = row.getValue(Usage)
        e = row.getValue(Age)
        #f = row.getValue(Btype)
    # Single family houses
        if d == 1 and e <= 1944:
            row.setValue("U_KD","1.2")
            rows.updateRow(row)
            row.setValue("U_OD","1.0")
            rows.updateRow(row)
            row.setValue("U_AW","2.0")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d == 1 and e > 1944 and e <= 1960:
            row.setValue("U_KD","1.95")
            rows.updateRow(row)
```

```
            row.setValue("U_OD","1.35")
            rows.updateRow(row)
            row.setValue("U_AW","1.75")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d == 1 and e > 1960 and e <= 1980:
            row.setValue("U_KD","1.35")
            rows.updateRow(row)
            row.setValue("U_OD","0.55")
            rows.updateRow(row)
            row.setValue("U_AW","1.2")
            rows.updateRow(row)
            row.setValue("U_FE","3.0")
            rows.updateRow(row)
        if d == 1 and e > 1980 and e <= 1990:
            row.setValue("U_KD","0.6")
            rows.updateRow(row)
            row.setValue("U_OD","0.3")
            rows.updateRow(row)
            row.setValue("U_AW","0.7")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d == 1 and e > 1990 and e <= 2000:
            row.setValue("U_KD","0.45")
            rows.updateRow(row)
            row.setValue("U_OD","0.3")
            rows.updateRow(row)
            row.setValue("U_AW","0.5")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d == 1 and e > 2000:
            row.setValue("U_KD","0.4")
            rows.updateRow(row)
            row.setValue("U_OD","0.2")
            rows.updateRow(row)
            row.setValue("U_AW","0.4")
            rows.updateRow(row)
            row.setValue("U_FE","1.9")
            rows.updateRow(row)

    # Mulit family houeses and non residential buildings
        if d != 1 and e <= 1944:
            row.setValue("U_KD","1.2")
            rows.updateRow(row)
            row.setValue("U_OD","1.0")
            rows.updateRow(row)
            row.setValue("U_AW","1.5")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d != 1 and e > 1944 and e <= 1960:
            row.setValue("U_KD","1.1")
            rows.updateRow(row)
            row.setValue("U_OD","1.35")
            rows.updateRow(row)
            row.setValue("U_AW","1.3")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d != 1 and e > 1960 and e <= 1980:
            row.setValue("U_KD","1.35")
            rows.updateRow(row)
            row.setValue("U_OD","0.55")
            rows.updateRow(row)
            row.setValue("U_AW","1.2")
            rows.updateRow(row)
            row.setValue("U_FE","3.0")
            rows.updateRow(row)
        if d != 1 and e > 1980 and e <= 1990:
            row.setValue("U_KD","0.6")
            rows.updateRow(row)
            row.setValue("U_OD","0.3")
            rows.updateRow(row)
            row.setValue("U_AW","0.7")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d != 1 and e > 1990 and e <= 2000:
            row.setValue("U_KD","0.45")
            rows.updateRow(row)
            row.setValue("U_OD","0.3")
            rows.updateRow(row)
            row.setValue("U_AW","0.5")
            rows.updateRow(row)
            row.setValue("U_FE","2.5")
            rows.updateRow(row)
        if d != 1 and e > 2000:
```

```
                    row.setValue("U_KD","0.4")
                    rows.updateRow(row)
                    row.setValue("U_OD","0.2")
                    rows.updateRow(row)
                    row.setValue("U_AW","0.5")
                    rows.updateRow(row)
                    row.setValue("U_FE","1.9")
                    rows.updateRow(row)

# Calculation of the heat transfer coefficient (LT,h,c):
            row.LTh = row.AW_real * row.U_AW * a + row.KD * row.U_KD * b + row.OD * row.U_OD * c + row.FE * row.U_FE
            rows.updateRow(row)

            row.LTc = row.AW_real * row.U_AW * a + row.KD * row.U_KD * b + row.OD * row.U_OD * 0 + row.FE * row.U_FE
            rows.updateRow(row)

# Calculation of the Transmisssion Heat Loss (QT):
            row.QTh = row.LTh * row.HDD * g
            rows.updateRow(row)

            row.QTc = row.LTc * row.CDD * g
            rows.updateRow(row)

            row.QT = row.QTh + row.QTc
            rows.updateRow(row)

except:
            arcpy.AddError("could not, zz...")
            arcpy.AddMessage(arcpy.GetMessages())
```

```
###########################################################################################
# Name: script2_QV_v2.py
# Author: Stefan M. (U1546)
#
# Description:
# Script assigns the effective air exchange rate values per building type, based on ÖNORM B8110-5
# and calculates the Energy Reference Area(AR) and the Related Air Volume (VV)
# After the Calculation of the Ventilation Heat Loss Coefficient (LV), the total amount of
# Ventilation losses will be calculated for heating and cooling (QV h,c)
#
# Requirements: # Energy Related Air Volume (m³), derived from Gross Floor
# Area and Storeys with default Height of 2.6m (ASI, 2002);
#
# Parameters:
# Heat Capacity of Air (1.006kJ/kgK), Density of Air (12kg/m³) -->
# --> Volume sourced heat capacity of air:  c(p,L) = 0.34Wh/(m³K);
# Effective Air Exchange Rate depends on Building Type (1/h);
# HDD and conversion factor per building;
#
# Output:
# The final output is the overall Ventilation Heat Loss (QV) per building.
##################################################################

# Import system modules
import arcpy
import sys
import string
import os
from arcpy import env

# Set environment settings
env.workspace = "C:\UniGIS\1 Master Thesis\3_Datasource\7_Projects\FinalDB.gdb"
arcpy.env.overwriteOutput = True

try:
      Inpath = arcpy.GetParameterAsText(0)           # Datasource
      ShapeArea = arcpy.GetParameterAsText(1)        # Building Footprint Area
      Floor = arcpy.GetParameterAsText(2)            # Number of Storeys
      Usage = arcpy.GetParameterAsText(3)            # building type
      RoomHeight = arcpy.GetParameterAsText(4)       # default value

      pl = arcpy.GetParameterAsText(5)               # Volume sour. heatcapacity of air
      cf = arcpy.GetParameterAsText(6)               # Conversion factor
      HDD = arcpy.GetParameterAsText(7)              # HDD per building
      CDD = arcpy.GetParameterAsText(8)              # CDD per building

# Variables
      a = float(RoomHeight)
      b = float(pl)
      d = float(cf)

# Add Fields for
      arcpy.AddField_management(Inpath,"NL","DOUBLE")
      arcpy.AddField_management(Inpath,"AR","DOUBLE")
      arcpy.AddField_management(Inpath,"VV","DOUBLE")
      arcpy.AddField_management(Inpath,"LVhc","DOUBLE")
      arcpy.AddField_management(Inpath,"QVh","DOUBLE")
```

```
        arcpy.AddField_management(Inpath,"QVc","DOUBLE")
        arcpy.AddField_management(Inpath,"QV","DOUBLE")

        rows = arcpy.UpdateCursor(Inpath)
        for row in rows:
        # Effective Air Exchange Rate per Building Type:
                e = row.getValue(Usage)
                if e == 1:
                        row.setValue("NL","0.4")
                        rows.updateRow(row)
                if e == 2:
                        row.setValue("NL","0.4")
                        rows.updateRow(row)
                if e == 3:
                        row.setValue("NL","0.4")
                        rows.updateRow(row)
                if e == 4:
                        row.setValue("NL","2.0")
                        rows.updateRow(row)
                if e == 5:
                        row.setValue("NL","2.0")
                        rows.updateRow(row)
                if e == 6:
                        row.setValue("NL","3.0")
                        rows.updateRow(row)
                if e == 7:
                        row.setValue("NL","2.0")
                        rows.updateRow(row)
                if e == 8:
                        row.setValue("NL","5.0")
                        rows.updateRow(row)
                if e == 9:
                        row.setValue("NL","3.0")
                        rows.updateRow(row)

# Calculation of Energy Reference Area(AR) and  Related Air Volume:
                FA = row.getValue(ShapeArea)
                ST = row.getValue(Floor)
                row.AR = FA * 0.8 * ST
                rows.updateRow(row)

                row.VV = row.AR * a
                rows.updateRow(row)

# Calculation of the heat ventilation coefficient (LVhc):
                row.LVhc = row.VV * b * row.NL
                rows.updateRow(row)

# Calculation of the Ventilation Heat Loss (QV):
                row.QVh = row.LVhc * row.getValue(HDD) * d
                rows.updateRow(row)

                row.QVc = row.LVhc * row.getValue(CDD) * d
                rows.updateRow(row)

                row.QV = row.QVh + row.QVc
                rows.updateRow(row)

except:
                arcpy.AddError("could not, zzzz...")
                arcpy.AddMessage(arcpy.GetMessages())
```

```
##########################################################################
# Name: script3_QI_v1.py
# Author: Stefan M. (U1546)
#
# Description:
# The script adds default Heat Gain Values (qi in W/m²) according to building type,
# based on ONÖRM B8110-6 (cf. ASI, 2010), and calculates the Energy Reference Area(AR).
# Finally, the Internal Heat Gain (QI h,c) for heating and cooling will be calculated.
#
# Requirements: # Energy Reference Area (m²), derived from Gross Floor
# Area and Storeys(ASI, 2002);
#
# Parameters:
# Internal Heat Gain per m²(AR)
# default value for residential buildings qi = 3.75W/m², used for all buildings
# HD and conversion factor;
#
# Output:
# Overall Internal Heat Gain (QI h,c) for heating and cooling per building.
##########################################################################

# Import system modules
import arcpy
import sys
import string
import os
```

```
from arcpy import env

# Set environment settings
env.workspace = "C:\UniGIS\1 Master Thesis\3_Datasource\7_Projects\FinalDB.gdb"
arcpy.env.overwriteOutput = True

try:
    Inpath = arcpy.GetParameterAsText(0)    # Datasource
    ShapeArea = arcpy.GetParameterAsText(1) # Gross Floor Area
    Usage = arcpy.GetParameterAsText(2)     # Building Type
    Floor = arcpy.GetParameterAsText(3)     # Num ber of Floors

    HeatingDays = arcpy.GetParameterAsText(4)  # Heating Days per year and building
    CoolingDays = arcpy.GetParameterAsText(5)  # Cooling Days per year and building
    cf = arcpy.GetParameterAsText(6)        # Conversion Factor

# Variables
    a = float(HeatingDays)
    b = float(CoolingDays)
    c = float(cf)

# Add Fields for
    arcpy.AddField_management(Inpath,"AR","DOUBLE")
    arcpy.AddField_management(Inpath,"qh","DOUBLE")
    arcpy.AddField_management(Inpath,"qc","DOUBLE")
    arcpy.AddField_management(Inpath,"QIh","DOUBLE")
    arcpy.AddField_management(Inpath,"QIc","DOUBLE")
    arcpy.AddField_management(Inpath,"QI","DOUBLE")

# Make the Updates:
    rows = arcpy.UpdateCursor(Inpath)
    for row in rows:
        d = row.getValue(Usage)
        if d in [1,2,3,5,6,7,9]:
            row.setValue("qh", "3.75")
            rows.updateRow(row)
        if d in [4,8]:
            row.setValue("qh", "7.5")
            rows.updateRow(row)
        if d in [1,2,3]:
            row.setValue("qc", "0")
            rows.updateRow(row)
        if d in [4,6,9]:
            row.setValue("qc", "7.5")
            rows.updateRow(row)
        if d in [5,7]:
            row.setValue("qc", "3.5")
            rows.updateRow(row)
        if d == 8:
            row.setValue("qc", "15")
            rows.updateRow(row)

# Calculation of Energy Reference Area:
        FA = row.getValue(ShapeArea)
        ST = row.getValue(Floor)
        row.AR = FA * 0.8 * ST
        rows.updateRow(row)

# Calculation of Heat Gain(QI), per building type:
        if f in [1,2,3]:
            row.QIh = row.AR * row.qh * a * c
            rows.updateRow(row)
            row.QIc = 0
            rows.updateRow(row)

        if f in [4,5,6,7,8,9]:
            row.QIh = row.AR * row.qh * a * c
            rows.updateRow(row)
            row.QIc = row.AR * row.qc * a * c
            rows.updateRow(row)

        row.QI = row.QIh + row.QIc
        rows.updateRow(row)
except:
    arcpy.AddError("could not, zzzzzzzz...")
    arcpy.AddMessage(arcpy.GetMessages())
```

```
##########################################################################
# Name: script4_QS_v2.py #
# Author: Stefan M. (U1546) #
#
# Description:
# The script adds new fields for Solar Effective Collecting Areas (Ag) first. Values for Solar
# Irradiation will be loaded from csv file into a python dictionary, to fetch
# individually data for further calculations. Then, the Solar Effective Collecting
# Area will be calculated, followed by the Calculation of the Solar Heat Gain (QS h,c),
# based on default values for building types (from ÖNORM B 8110-5)for # heating(September-April)
# and cooling season (May-August).
```

```
#
# Assumptions: no window fraction for industrial buildings and storage rooms;
# Inclination for all windows is 90°;
# g-value = 0.75, which refers to uncoated double isolation glazing (cf. ASi, 2010);

# Requirements:
# Window Area, per Orientation and Building (see process in chapter Solar Irradiance(SI)–Orientation
# Ij ... Total Solar Irradiance per m² (kWh/m) with an Orientation j
# Ag ... Solar Effective Area (m²) (= Window Area*0.7)
# gw ... Solar effective g-value
# Fs ... Shading Reduction Factor
#
# Parameters:
# Shading Reduction Factor (SFH/MFH --> 0.85/0.75 for heating)
# In case of cooling demand the shading reduction factor is 1.
# Solar effective g-value (g=0.75, uncoated double isolation glazing, ASI, 2010)

# Output:
# The overall Solar Heat Gain (QS h,c) per Building and Year.
###############################################################################
# Import system modules
from arcpy import env
import sys
import string
import os
import csv
from collections import defaultdict

# Set environment settings
env.workspace = "C:\UniGIS\1 Master Thesis\3_Datasource\7_Projects\FinalDB.gdb"
arcpy.env.overwriteOutput = True

try:
# Script Input Values
    Inpath = arcpy.GetParameterAsText(0)    # Building Feature Class
    GValue = arcpy.GetParameterAsText(1)    # g-value (cf. gw=0.9*0.98*g)
    Usage = arcpy.GetParameterAsText(2)     # Building Usage
    Inpath2 = arcpy.GetParameterAsText(3)   # Monthly Solar Irradiance, as csv File
    ShReFa_SFH = arcpy.GetParameterAsText(4)    # Shading reducton Factor SFH (0.85)
    ShReFa_MFH = arcpy.GetParameterAsText(5)    # Shading reducton Factor SFH (0.75)


# Add new Fields --> Solar Effective Area (Ag)
    arcpy.AddField_management(Inpath,"AgN","DOUBLE")
    arcpy.AddField_management(Inpath,"AgNNE_NNW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgNE_NW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgENE_WNW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgE_W","DOUBLE")
    arcpy.AddField_management(Inpath,"AgESE_WSW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgSE_SW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgSSE_SSW","DOUBLE")
    arcpy.AddField_management(Inpath,"AgS","DOUBLE")
    arcpy.AddField_management(Inpath,"QSh","DOUBLE") # Annual Solar Heat Gain
    arcpy.AddField_management(Inpath,"QSc","DOUBLE") # Annual Solar Heat Gain
    arcpy.AddField_management(Inpath,"QS","DOUBLE") # Annual Solar Heat Gain

# other Variables
    a = 0.7             # default glass ratio --> 0.7
    b = float(GValue)   # g-value (default; uncoated 2x isolation glazing --> 0.75)
    e = b*0.9*0.98      # gw
# Shading reduction Factors
    x = float(ShReFa_SFH)
    y = float(ShReFa_MFH)
    # z = 1

# Make the Updates for Solar Effective Area Ag:
    rows = arcpy.UpdateCursor(Inpath)

 # load SI csv into dictionary
    columns = defaultdict(list) # each value in each column is appended to a list
    with open('C:/UniGIS/1 Master Thesis/3_Datasource/7_Projects/1_Excel/SI_Month.csv', 'rb')  as f:
        reader = csv.DictReader(f) # read rows into a dictionary format
        for row in reader: # read a row as {column1: value1, column2: value2,...}
            for (k,v) in row.items(): # go over each column name and value
                columns[k].append(v) # append the value into the appropriate list
                                     # based on column name k

# monthly solar irradiation per cardinal point, in columns: (0 = N, 1 = NNE_NNW, ..., 8 = S)
    jan = [float(i) for i in (columns['January'][0:])]
    feb = [float(i) for i in (columns['February'][0:])]
    mar = [float(i) for i in (columns['March'][0:])]
    apr = [float(i) for i in (columns['April'][0:])]
    may = [float(i) for i in (columns['May'][0:])]
    jun = [float(i) for i in (columns['June'][0:])]
    jul = [float(i) for i in (columns['July'][0:])]
    aug = [float(i) for i in (columns['August'][0:])]
    sep = [float(i) for i in (columns['September'][0:])]
    oct = [float(i) for i in (columns['October'][0:])]
    nov = [float(i) for i in (columns['November'][0:])]
    dec = [float(i) for i in (columns['December'][0:])]
```

```
# Calculate Solar Effective Collecting Area
   for row in rows:
      f = row.getValue("N")
      row.AgN = f*a
      rows.updateRow(row)

      g = row.getValue("NNE_NNW")
      row.AgNNE_NNW = g*a
      rows.updateRow(row)

      h = row.getValue("NE_NW")
      row.AgNE_NW = h*a
      rows.updateRow(row)

      i = row.getValue("ENE_WNW")
      row.AgENE_WNW = i*a
      rows.updateRow(row)

      j = row.getValue("E_W")
      row.AgE_W = j*a
      rows.updateRow(row)

      k = row.getValue("ESE_WSW")
      row.AgESE_WSW = k*a
      rows.updateRow(row)

      l = row.getValue("SE_SW")
      row.AgSE_SW = l*a
      rows.updateRow(row)

      m = row.getValue("SSE_SSW")
      row.AgSSE_SSW = m*a
      rows.updateRow(row)

      n = row.getValue("S")
      row.AgS = n*a
      rows.updateRow(row)

   # select Building Type:

      d = row.getValue(Usage)
      # Calculation of the Solar Heat Gain(QS)
      if d in [1,2]: # Single family, double family and row houses (heating --> 0.85)
         row.QSh =(row.AgN*e*x)*jan[0]+(row.AgN*e*x)*feb[0]+(row.AgN*e*x)*mar[0]+(row.AgN*e*x)*apr[0]\
               +(row.AgN*e*x)*sep[0]+(row.AgN*e*x)*oct[0]+(row.AgN*e*x)*nov[0]+(row.AgN*e*x)*dec[0]\

+(row.AgNNE_NNW*e*x)*jan[1]+(row.AgNNE_NNW*e*x)*feb[1]+(row.AgNNE_NNW*e*x)*mar[1]+(row.AgNNE_NNW*e*x)*apr[1]\

+(row.AgNNE_NNW*e*x)*sep[1]+(row.AgNNE_NNW*e*x)*oct[1]+(row.AgNNE_NNW*e*x)*nov[1]+(row.AgNNE_NNW*e*x)*dec[1]\
               +(row.AgNE_NW*e*x)*jan[2]+(row.AgNE_NW*e*x)*feb[2]+(row.AgNE_NW*e*x)*mar[2]+(row.AgNE_NW*e*x)*apr[2]\
               +(row.AgNE_NW*e*x)*sep[2]+(row.AgNE_NW*e*x)*oct[2]+(row.AgNE_NW*e*x)*nov[2]+(row.AgNE_NW*e*x)*dec[2]\

+(row.AgENE_WNW*e*x)*jan[3]+(row.AgENE_WNW*e*x)*feb[3]+(row.AgENE_WNW*e*x)*mar[3]+(row.AgENE_WNW*e*x)*apr[3]\

+(row.AgENE_WNW*e*x)*sep[3]+(row.AgENE_WNW*e*x)*oct[3]+(row.AgENE_WNW*e*x)*nov[3]+(row.AgENE_WNW*e*x)*dec[3]\
               +(row.AgE_W*e*x)*jan[4]+(row.AgE_W*e*x)*feb[4]+(row.AgE_W*e*x)*mar[4]+(row.AgE_W*e*x)*apr[4]\
               +(row.AgE_W*e*x)*sep[4]+(row.AgE_W*e*x)*oct[4]+(row.AgE_W*e*x)*nov[4]+(row.AgE_W*e*x)*dec[4]\

+(row.AgESE_WSW*e*x)*jan[5]+(row.AgESE_WSW*e*x)*feb[5]+(row.AgESE_WSW*e*x)*mar[5]+(row.AgESE_WSW*e*x)*apr[5]\

+(row.AgESE_WSW*e*x)*sep[5]+(row.AgESE_WSW*e*x)*oct[5]+(row.AgESE_WSW*e*x)*nov[5]+(row.AgESE_WSW*e*x)*dec[5]\
               +(row.AgSE_SW*e*x)*jan[6]+(row.AgSE_SW*e*x)*feb[6]+(row.AgSE_SW*e*x)*mar[6]+(row.AgSE_SW*e*x)*apr[6]\
               +(row.AgSE_SW*e*x)*sep[6]+(row.AgSE_SW*e*x)*oct[6]+(row.AgSE_SW*e*x)*nov[6]+(row.AgSE_SW*e*x)*dec[6]\
               +(row.AgSSE_SSW*e*x)*jan[7]+(row.AgSSE_SSW*e*x)*feb[7]+(row.AgSSE_SSW*e*x)*mar[7]+(row.AgSSE_SSW*e*x)*apr[7]\
               +(row.AgSSE_SSW*e*x)*sep[7]+(row.AgSSE_SSW*e*x)*oct[7]+(row.AgSSE_SSW*e*x)*nov[7]+(row.AgSSE_SSW*e*x)*dec[7]\
               +(row.AgS*e*x)*jan[8]+(row.AgS*e*x)*feb[8]+(row.AgS*e*x)*mar[8]+(row.AgS*e*x)*apr[8]\
               +(row.AgS*e*x)*sep[8]+(row.AgS*e*x)*oct[8]+(row.AgS*e*x)*nov[8]+(row.AgS*e*x)*dec[8]
         rows.updateRow(row)

         # Single family, double family and row houses (cooling --> 1)
         row.QSc =(row.AgN*e)*may[0]+(row.AgN*e*0.85)*jun[0]+(row.AgN*e*0.85)*jul[0]+(row.AgN*e*0.85)*aug[0]\

+(row.AgNNE_NNW*e*0.85)*may[1]+(row.AgNNE_NNW*e*0.85)*jun[1]+(row.AgNNE_NNW*e*0.85)*jul[1]+(row.AgNNE_NNW*e*0.85)*aug
[1]\

+(row.AgNE_NW*e*0.85)*may[2]+(row.AgNE_NW*e*0.85)*jun[2]+(row.AgNE_NW*e*0.85)*jul[2]+(row.AgNE_NW*e*0.85)*aug[2]\

+(row.AgENE_WNW*e*0.85)*may[3]+(row.AgENE_WNW*e*0.85)*jun[3]+(row.AgENE_WNW*e*0.85)*jul[3]+(row.AgENE_WNW*e*0.85)*au
g[3]\
               +(row.AgE_W*e*0.85)*may[4]+(row.AgE_W*e*0.85)*jun[4]+(row.AgE_W*e*0.85)*jul[4]+(row.AgE_W*e*0.85)*aug[4]\

+(row.AgESE_WSW*e*0.85)*may[5]+(row.AgESE_WSW*e*0.85)*jun[5]+(row.AgESE_WSW*e*0.85)*jul[5]+(row.AgESE_WSW*e*0.85)*aug[5
]\
               +(row.AgSE_SW*e*0.85)*may[6]+(row.AgSE_SW*e*0.85)*jun[6]+(row.AgSE_SW*e*0.85)*jul[6]+(row.AgSE_SW*e*0.85)*aug[6]\

+(row.AgSSE_SSW*e*0.85)*may[7]+(row.AgSSE_SSW*e*0.85)*jun[7]+(row.AgSSE_SSW*e*0.85)*jul[7]+(row.AgSSE_SSW*e*0.85)*aug[7]\
               +(row.AgS*e*0.85)*may[8]+(row.AgS*e*0.85)*jun[8]+(row.AgS*e*0.85)*jul[8]+(row.AgS*e*0.85)*aug[8]
         rows.updateRow(row)
```

```
# other houses (--> 0.75)
      if d in [3,4,5,6,7,9]:
         row.QSh =(row.AgN*e*y)*jan[0]+(row.AgN*e*y)*feb[0]+(row.AgN*e*y)*mar[0]+(row.AgN*e*y)*apr[0]\
               +(row.AgN*e*y)*sep[0]+(row.AgN*e*y)*oct[0]+(row.AgN*e*y)*nov[0]+(row.AgN*e*y)*dec[0]\

+(row.AgNNE_NNW*e*y)*jan[1]+(row.AgNNE_NNW*e*y)*feb[1]+(row.AgNNE_NNW*e*y)*mar[1]+(row.AgNNE_NNW*e*y)*apr[1]\

+(row.AgNNE_NNW*e*y)*sep[1]+(row.AgNNE_NNW*e*y)*oct[1]+(row.AgNNE_NNW*e*y)*nov[1]+(row.AgNNE_NNW*e*y)*dec[1]\
               +(row.AgNE_NW*e*y)*jan[2]+(row.AgNE_NW*e*y)*feb[2]+(row.AgNE_NW*e*y)*mar[2]+(row.AgNE_NW*e*y)*apr[2]\
               +(row.AgNE_NW*e*y)*sep[2]+(row.AgNE_NW*e*y)*oct[2]+(row.AgNE_NW*e*y)*nov[2]+(row.AgNE_NW*e*y)*dec[2]\

+(row.AgENE_WNW*e*y)*jan[3]+(row.AgENE_WNW*e*y)*feb[3]+(row.AgENE_WNW*e*y)*mar[3]+(row.AgENE_WNW*e*y)*apr[3]\

+(row.AgENE_WNW*e*y)*sep[3]+(row.AgENE_WNW*e*y)*oct[3]+(row.AgENE_WNW*e*y)*nov[3]+(row.AgENE_WNW*e*y)*dec[3]\
               +(row.AgE_W*e*y)*jan[4]+(row.AgE_W*e*y)*feb[4]+(row.AgE_W*e*y)*mar[4]+(row.AgE_W*e*y)*apr[4]\
               +(row.AgE_W*e*y)*sep[4]+(row.AgE_W*e*y)*oct[4]+(row.AgE_W*e*y)*nov[4]+(row.AgE_W*e*y)*dec[4]\

+(row.AgESE_WSW*e*y)*jan[5]+(row.AgESE_WSW*e*y)*feb[5]+(row.AgESE_WSW*e*y)*mar[5]+(row.AgESE_WSW*e*y)*apr[5]\

+(row.AgESE_WSW*e*y)*sep[5]+(row.AgESE_WSW*e*y)*oct[5]+(row.AgESE_WSW*e*y)*nov[5]+(row.AgESE_WSW*e*y)*dec[5]\
               +(row.AgSE_SW*e*y)*jan[6]+(row.AgSE_SW*e*y)*feb[6]+(row.AgSE_SW*e*y)*mar[6]+(row.AgSE_SW*e*y)*apr[6]\
               +(row.AgSE_SW*e*y)*sep[6]+(row.AgSE_SW*e*y)*oct[6]+(row.AgSE_SW*e*y)*nov[6]+(row.AgSE_SW*e*y)*dec[6]\
               +(row.AgSSE_SSW*e*y)*jan[7]+(row.AgSSE_SSW*e*y)*feb[7]+(row.AgSSE_SSW*e*y)*mar[7]+(row.AgSSE_SSW*e*y)*apr[7]\
               +(row.AgSSE_SSW*e*y)*sep[7]+(row.AgSSE_SSW*e*y)*oct[7]+(row.AgSSE_SSW*e*y)*nov[7]+(row.AgSSE_SSW*e*y)*dec[7]\
               +(row.AgS*e*y)*jan[8]+(row.AgS*e*y)*feb[8]+(row.AgS*e*y)*mar[8]+(row.AgS*e*y)*apr[8]\
               +(row.AgS*e*y)*sep[8]+(row.AgS*e*y)*oct[8]+(row.AgS*e*y)*nov[8]+(row.AgS*e*y)*dec[8]
         rows.updateRow(row)

         row.QSc = (row.AgN*e)*may[0]+(row.AgN*e)*jun[0]+(row.AgN*e)*jul[0]+(row.AgN*e)*aug[0]\
               +(row.AgNNE_NNW*e)*may[1]+(row.AgNNE_NNW*e)*jun[1]+(row.AgNNE_NNW*e)*jul[1]+(row.AgNNE_NNW*e)*aug[1]\
               +(row.AgNE_NW*e)*may[2]+(row.AgNE_NW*e)*jun[2]+(row.AgNE_NW*e)*jul[2]+(row.AgNE_NW*e)*aug[2]\
               +(row.AgENE_WNW*e)*may[3]+(row.AgENE_WNW*e)*jun[3]+(row.AgENE_WNW*e)*jul[3]+(row.AgENE_WNW*e)*aug[3]\
               +(row.AgE_W*e)*may[4]+(row.AgE_W*e)*jun[4]+(row.AgE_W*e)*jul[4]+(row.AgE_W*e)*aug[4]\
               +(row.AgESE_WSW*e)*may[5]+(row.AgESE_WSW*e)*jun[5]+(row.AgESE_WSW*e)*jul[5]+(row.AgESE_WSW*e)*aug[5]\
               +(row.AgSE_SW*e)*may[6]+(row.AgSE_SW*e)*jun[6]+(row.AgSE_SW*e)*jul[6]+(row.AgSE_SW*e)*aug[6]\
               +(row.AgSSE_SSW*e)*may[7]+(row.AgSSE_SSW*e)*jun[7]+(row.AgSSE_SSW*e)*jul[7]+(row.AgSSE_SSW*e)*aug[7]\
               +(row.AgS*e)*may[8]+(row.AgS*e)*jun[8]+(row.AgS*e)*jul[8]+(row.AgS*e)*aug[8]
         rows.updateRow(row)

      if d == 8:   # Industrial Buildings and Storage Rooms (assumed no Windows)
         row.QSh = 0
         rows.updateRow(row)
         row.QSc = 0
         rows.updateRow(row)

      row.QS = row.QSh + row.QSc
      rows.updateRow(row)
except:
      arcpy.AddError("could not, zzzzzzzzzzzzzzzz ...")
      arcpy.AddMessage(arcpy.GetMessages())
```

```
##########################################################################
# Name: script5.py
# Author: Stefan M. (U1546)
#
# Description:
# Calculates the total amount of the annual Heating (HD) and Cooling Demand (CD)
# per building and year.
#
# Requirements:
# Results from the previous 4 scripts.
# Gross Floor Area
# Utilization factor n
#
# Output:
# Total amount of Heating/Cooling Demand per building and Year in kWh/a.
# Specific Heating/Cooling Demand in kWh/m²a.
#
# Parameters:
# Utilization factor n = 0.95 (cf. OIB, 1999)
###########################################################################
# Import system modules
from arcpy import env
import sys
import string
import os

# Set environment settings
env.workspace = "C:\UniGIS\1 Master Thesis\3_Datasource\7_Projects\FinalDB.gdb"
arcpy.env.overwriteOutput = True

try:
# Script Input Values
   Inpath = arcpy.GetParameterAsText(0)    # Building Feature Class
   AR = arcpy.GetParameterAsText(1)     # Gross Floor Area
   uf = arcpy.GetParameterAsText(2)     # Utilization Factor (default: 0.95, cf. OIB, 1999)

# Add new Fields --> Solar Effective Area Ag)
```

```
    arcpy.AddField_management(Inpath,"Qhloss","DOUBLE")
    arcpy.AddField_management(Inpath,"Qhgain","DOUBLE")
    arcpy.AddField_management(Inpath,"Qheating","DOUBLE")
    arcpy.AddField_management(Inpath,"Qcloss","DOUBLE")
    arcpy.AddField_management(Inpath,"Qcgain","DOUBLE")
    arcpy.AddField_management(Inpath,"Qcooling","DOUBLE")
    arcpy.AddField_management(Inpath,"HD","DOUBLE")    # specicic heating energy demand
    arcpy.AddField_management(Inpath,"CD","DOUBLE")    # specicic cooling energy demand

# Variables
    rows = arcpy.UpdateCursor(Inpath)
    n = float(uf)
# Calculates the annual Heating and Cooling Demand
    for row in rows:
        # Heating
        row.Qhloss = row.QTh + row.QVh
        rows.updateRow(row)
        row.Qhgain = row.QIh + row.QSh
        rows.updateRow(row)

        # Cooling
        row.Qcloss = row.QTc + row.QVc
        rows.updateRow(row)
        row.Qcgain = row.QIc + row.QSc
        rows.updateRow(row)

        # Annual Heating Demand
        row.Qheating = row.Qhloss - n * row.Qhgain
        rows.updateRow(row)

        # Annual Cooling Demand
        row.Qcooling = row.Qcloss + row.Qcgain
        rows.updateRow(row)

    # Calculation of Specific Energy Demand (HD, CD):
        GFA = row.getValue(AR)

    # for all Buildings:
        row.HD = row.Qheating/GFA
        rows.updateRow(row)

        row.CD = row.Qcooling/GFA
        rows.updateRow(row)

except:
        arcpy.AddError("could not, zzzzzzzzzzzz....")
        arcpy.AddMessage(arcpy.GetMessages())
```