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Energy and Space
The Implication of Spatial Planning on Energy Demand and Energy Efficiency Potentials

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, February 23, 2012

Affidavit

I, **Nathalie Wergles**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Energy and Space. The Implication of Spatial Planning on Energy Demand and Energy Efficiency Potentials", 176 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

HOW WE ARRANGE our activities (e.g., dwelling, work, education, leisure, mobility, etc.) in space has implications on energy demand and on energy efficiency potentials. Low density, sprawling development and monofunctional land use are generally thought to increase energy demand. However, findings indicate that density does not always (significantly) decrease energy consumption and the role of traffic in energy demand related to land use and urban density remains a contested issue.

Land use and spatial planning affect many aspects of household energy demand. Land use planning intervenes on the level of settlement structures and building types, all of which has implications on the demand for heating, cooling, and illumination. Land use patterns and settlement structures also impact energy demand by increasing both the demand for technical infrastructure and public-distributive services and the demand for (private) motorized mobility.

The purpose of this paper is to discuss the various potential implications of urbanization and land use patterns on household primary energy demand and to identify aspects of household energy demand that can be clearly linked to spatial structures of landuse. Furthermore, the objective is to develop a theoretical model for the assessment and quantification of land use and spatial pattern related energy demand. This involves the development of an indicator for urban form and function which can be used to compare different land use patterns in the Austrian context, and the description of required input parameters and data sources regarding availability and data quality.

The analysis is split into a separate analysis of the subsystems 'energy demand related to dwelling', 'energy demand related to the provision of technical and public-distributive infrastructure', and 'energy demand for mobility' and a methodology was developed for each of the three subsystems. Settlement structure is operationalized by proposing a matrix classification for settlements that combines functional aspects of land use and morphological aspects of spatial patterns.

Suitable assessment methods were identified for the assessment of building, technical infrastructure, and transport energy demand. Difficulties relate to finding the optimal trade off between necessary accuracy, on the one hand, and the applicability and comprehensiveness of the approach, on the other hand. Methods must be sensitive to even subtle relative differences between the settlement classes and be suited for a large representative sample, thus go beyond the application to few case studies. Furthermore, energy demand is difficult to disentangle from socio-economic variables that influence energy consumption patterns and from lifestyles and personal attitudes which must be controlled in order to avoid erroneous conclusions. Regarding data input, parts of the required input data are available in the necessary quality and spatio-temporal resolution. Data restrictions are related to the fact that some data are only available in aggregated format, outdated or not publicly accessible due to requirements on data protection. Lack of data concerns mobility behaviour and specific fuel consumption of public means of transport.

The outcome of these findings was formalised in a theoretical model that restricts its focus to the typical average annual household primary energy demand for building and vehicle use, without accounting for upstream processes, and the typical annual primary energy demand of communities related to the provision of technical infrastructure for the total energy embodied in the process from production to disposal.

More groundwork has to be done before the method can be readily implemented. Generally, the different methodological approaches for the assessment of primary energy demand must be validated by comparing results from samples with measured values. Input parameters for the settlement classification must be reviewed and the classification scheme should be subjected to practical testing.

In the next step, the proposed method should be subject to testing and be implemented in a number of case studies.

Acknowledgements

"Feeling gratitude and not expressing it

is like wrapping a present and not giving it."

William Arthur Ward

According to Austrian university law, a master's thesis is the demonstration of a student's ability to carry out independent scientific work. In reality, a thesis relies on the support and cooperation of a number of people. The 'Acknowledgements' are hence the perfect opportunity to put those in the limelight who, beside the student, significantly contributed – morally or materially – to the successfully finished thesis.

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1 Introduction

HOW WE ARRANGE our activities (e.g., dwelling, work, education, leisure, mobility, etc.) in space has implications on our energy demand and on energy efficiency potentials. Spatial implications concern energy production (e.g., the spatial impact of the use of renewable energy carriers which imply a more regionalised energy provision) as well as energy consumption (e.g., the increase in traffic volume due to rural sprawl and suburbanisation).

EU 20-20-20 target

While this relationship is common-sensical, the extent of contribution of current spatial planning practices to the overall energy demand of Austrian households remains unclear. However, in light of the scarcity of energy resources, the need to cut greenhouse gases to mitigate climate change, the sustainability debate in general, and the commitment of the EU council to reduce greenhouse gases by 20%, to reach 20% of renewable energy, and increase energy efficiency all by 20% by 2020 the topic of energy efficiency has received new impetus. The Austrian National Energy Strategy recognizes that energy efficiency is the key to Austrian energy policy and that so far the discussion was too much centred on the supply side and too little focused on energy efficiency potentials on the demand side.

10 to 30% additional energy demand

Land use and spatial planning affect many aspects of household energy demand. Land use planning intervenes on the level of settlement structures and building types, all of which has implications on the demand for heating, cooling, and illumination. Land use patterns and settlement structures also impact energy demand by increasing both the demand for technical infrastructure and public-social distributive services and the demand for (private) motorized mobility. Most studies report a significant correlation between urban density and (primary) energy demand for dwelling, infrastructure, and mobility, indicating that the effect is not negligible. For Switzerland, the contribution of settlement types on primary energy demand was estimated at 10 to 30% compared to the densest (urban) settlement and depending on the type of density parameter used. In practical terms, this means additional 2,000 to 6,100 kWh per capita for an average annual per capita final energy consumption of 20,350 kWh[1]. For Austria, the order of magnitude of energy implications in relation to urban density is probably similar to Switzerland or even higher given that misguided spatial planning practices of the past decades have strongly encouraged unsustainable low-density residential development. However, despite strong evidence, the land use-energy demand nexus remains a contested issue. First of all, the controversy revolves around the fact that, while establishing correlation, most studies fail to demonstrate causality. Secondly, most studies do not take sufficient account of the fact that there are numerous factors influencing energy demand and that modelling energy demand is sensitive to small changes in assumptions and boundary conditions. Furthermore, the majority of studies refer to final energy without accounting for conversion and distribution losses, which leads to a distortion of results and conceals the actual order of magnitude.

research objective

The purpose of this paper is therefore to discuss the various potential implications of urbanization and land use patterns on household primary energy demand and to develop a theoretical model and method that allows a quantification of energy efficiency potenti-

[1] Survey energy consumption of Austrian households. Only energy consumed for space heat, hot water, illumination, and mobility included. Source: (Bohunovsky, Grünberger, Frühmann & Hinterberger, 2010)

als related to land use and to describe required input parameters with specific reference to available data sources.

With these objectives in mind, this paper proceeds as follows: chapter 3 presents research objectives and research questions. Chapter 2 situates the topic in the context of energy efficiency requirements arising from the need to decrease energy consumption and from legislation. An overview of (household) final energy use in Austria is given and spatial planning practices which favour land consuming housing development associated with higher energy demand for mobility, housing, and public services are analysed. Chapter 4 proposes a framework for assessing the implications of spatial planning on primary energy demand. The system boundaries are defined and methods and data sources for determining the primary energy demand related to dwelling, technical and public-distributive infrastructure, and mobility are described. The most important findings are consequently discussed in chapter 5 which provides some concluding remarks and an outlook on future research.

Fig. 1: Rural sprawl.

2 Research Objectives and Questions

IN AUSTRIA, the topic of energy-efficient land use was brought up first in the context of the climate change and sustainability discussion and received a strong impulse when the EU-wide target of 20% increase in energy efficiency by 2020 became binding for all member states.

In 2006, the Austrian Conference on Regional Planning (ÖROK) started a project on the contribution of spatial development to securing energy supply and reducing energy demand and commissioned a preliminary study to identify research gaps (ÖROK, 2007). According to this study, open research questions concern, among others, the identification of energy and space saving and cost efficient spatial structures (on the level of zoning and building regulation plans) and of suitable planning instruments for providing the necessary incentives or dissuasive effect to achieve them.

The study admits that there is high uncertainty regarding the actual impact of settlement structures on energy consumption and that it is by no means clear, which settlement structures are most energy efficient. Findings indicate that density does not always (significantly) decrease consumption. Lack of knowledge also relates to whether spatial planning can influence mobility behaviour for the benefit of higher energy efficiency and how location decisions can be coupled with energy efficient spatial structures at the local level.

The interaction between land use patterns and urban form, on the one hand, and energy demand, on the other hand, is a complex relationship involving many different parameters. Land use planning intervenes on the level of settlement structures and building types, all of which has implications on the demand for heating, cooling, and illumination. Land use patterns and urban structures also impact energy demand by increasing both the demand for technical infrastructure and public-social distributive services and the demand for (private) motorized mobility.

energy–land use nexus

However, while the generally accepted hypothesis implies that urban density and energy demand are negatively correlated, meaning that energy demand grows with decreasing density, the magnitude of the effect is unclear for a number of reasons. First of all, the relationship between land use and energy demand is not a simple cause-and-effect relation. Mobility behaviour, for example, can be only to some extent explained by the local supply situation or availability (resp. lack) of alternative public transportations modes. Improving local supply with goods and services and promoting public transportation will avoid or redistribute only some of the car traffic. Additional interventions are necessary, targeting at the cost of private motorized transport, such as the price of gasoline or parking (Pischinger, 1998). Secondly, the relationship is subject to rebound effects. To take again mobility as an example, it is known that, as people become more mobile, larger distances are more readily accepted and goods and services are consumed in varying places – a behaviour termed "polyorientation" (Weichhart, 1996). A second observation is that, while the dichotomy between "the city" and the "hinterland" is no longer valid, there are still marked differences in urban and rural lifestyles. The population in rural areas is more dependent on the availability of a private car; however, this car dependency is part of the reason why the percent of working women in rural areas is lower. Rural population may dwell in larger (detached single-family) houses, however, it is also true that households are generally larger, decreasing the living space per capita and, hence, the energy demand per capita for, e.g., heating. Single households, on the contrary, which have a larger average per capita living space, are mainly found in cities. Thirdly, energy demand is difficult to disentangle from socio-economic variables that influence energy consumption patterns, such as income or level of education, and from lifestyles and personal attitudes, such as travel behaviour or environmental awareness. Bohunovsky et al. (2010) find that households with above-average education and high income use energy efficient appliances and tend to live in a building with low energy demand, but compensate these energy savings by owning more appliances and a larger living space or by showing a more energy-consuming mobility and travel behaviour. Low-income households, on the other hand, use heating energy and electricity in a more inefficient way, but are less mobile or use more energy-efficient modes of travelling. And lastly, the relationship is sensitive to small changes in the input parameters. Here, technical efficiency aspects come into play: the energy demand for dwelling depends to a large extent on the quality of thermal insulation of the building shell and insulating quality of the windows and on the efficiency of technical building systems (Jochum & Pehnt, 2010). The energy demand for mobility is also not only a result of the annual mileage of a car, but depends significantly on the efficiency of the car engine. Therefore, the result of the modelling is highly sensitive towards the assumptions made, in particular those regarding technical energy efficiencies and losses. It follows that a serious and reliable result can only be obtained through careful modelling and the use of a sensitivity analysis to study the robustness of the result and susceptibility to variations in the inputs of the model.

benefits of research

Hence, several benefits can be drawn from research on the contribution of land use and spatial patterns on energy demand. Research can

- provide understanding on the interrelation between land use and energy demand and knowledge on energy saving potentials in the area of spatial planning practices and policies,
- contribute to policy making in the field of spatial planning, land use policies and transport management by demonstrating the impact of compact settlements and mixed land use on energy demand for dwelling, technical and public infrastructure, and household mobility,
- promote a targeted and efficient use of subsidies and financial resources,
- support the implementation of measures targeted at land use planning and traffic and mobility management proposed in the National Energy Strategy and the achievement of the envisaged energy efficiency goals, and
- enable the development of a modelling tool for making future projections on land use related energy demand and define and compare different scenarios for different time horizons (e.g., different scenarios of technological progress or urban development).

research objectives

The objective of this paper is, therefore, to

- identify aspects of household energy demand that can be clearly linked to spatial structures of landuse,
- develop an indicator for urban form and function which can be used to compare different land use patterns in the Austrian context,
- develop a theoretical model for the assessment of land use and spatial pattern related energy demand and describe the input parameters with specific reference to available data sources, and
- describe data sources regarding availability and data quality in terms of timeliness and completeness.

This raises questions about the parameters involved and about how they can be operationalized and quantified, about possible data sources, and about existing assessment methods for building energy demand, transport energy demand, and energy demand for technical and public infrastructure. Research questions can be boiled down to three central questions:

research questions

1. What are the implications of land use and spatial structure on household energy demand and how can they be quantified?
2. What are the relations between parameters and how can they be formalised in a model?
3. What are necessary (and existing) data sources for their quantification?

energy demand versus energy consumption

final energy versus primary energy

The focus of the study shall be restricted to those aspects of energy demand which are supposed to be influenced by land use and spatial patterns and that can be attributed to households. Industry's and companies' energy demand may also be affected by land use but remain outside the defined system boundary as they have very distinct energy consumption patterns. Furthermore, the study shall explicitly refer to energy demand, as the theoretical energy need under the given assumptions, as opposed to energy consumption, which refers to the actually consumed amount of energy. The strong influence of socio-economic household characteristics speaks against the use of actual energy consumption data. To allow the addition and comparison of different types of energies, final energy demand is converted to primary energy and all values are related to per capita demand. Thus, 'energy demand' throughout the paper refers to specific primary energy demand per capita, unless otherwise specified.

3 Context and Background

3.1 Energy Consumption in Austria

AUSTRIAN GROSS ENERGY consumption has increased continuously in the last decades and rose by 83% between 1970 and 2005 to 1,456 PJ (405 TWh) in 2005 and since then decreased slightly, with a considerable decrease to 1,354 PJ (376 TWh) in 2009 due to the economic recession (Statistik Austria, 2010a). Cutting its energy use by 20%, Austria is committed to achieve the target value of 1,100 PJ (306 TWh) by 2020 (BMWFJ, 2010b). Characteristically, Austria is highly dependent on the import of fossil fuels and the import dependency of its energy supply is significantly above the average of the EU-27. In terms of figures, this means that about two thirds of the energy demanded has to be imported.

Austrian energy balance

The Austrian energy balance gives a first idea of the breakdown of energy consumption by sector. Statistical data are aggregated following the format of the European Statistical Office and distinguish between industry (excluding the 'energy' branch), transport, and service & private households (Tab. 1). In 2009 industry was responsible for 29%, transport for 34%, and services and households for 37% of energy end use. The latter two are the most important sectors for analysing the implication of land use on energy consumption. Transport and private households therefore need to be analysed in greater depth.

Tab. 1: Breakdown of final energy consumption by sector for 2009 values. Values in TJ and converted to GWh.

FINAL ENERGY CONSUMPTION BY SECTOR (values in TJ and GWh are for 2009)			
Industry	307,730 TJ	85,480 GWh	29,11%
Iron and steel	40,602	11,278	
Non-ferrous metals	7,708	2,141	
Chemical industry	37,725	10,479	
Non-metallic mineral products	41,135	11,426	
Vehicle engineering	5,687	1,580	
Mechanical engineering	22,115	6,143	
Ore-extraction (except fuels)	4,503	1,251	
Food, drink and tobacco	22,446	6,235	
Textile, leather and clothing	4,063	1,129	
Pulp, paper and printing	63,681	17,689	
Timber processing industry	25,827	7,174	
Construction	22,582	6,273	
Other non-classified	9,656	2,682	
Transport	357,252 TJ	99,237 GWh	33,79%
Railway	8,517	2,366	0,81%
Road transport	312,506	86,807	29,56%
Transport by pipeline	8,242	2,290	0,78%
Transport on inland waterways	456	127	0,04%
Air traffic	27,532	7,648	2,60%
Services and households	392,289 TJ	108,969 GWh	37,10%
Public and private services	109,128	30,313	10,32%
Private households	260,932	72,481	24,68%
Agriculture	22,229	6,175	2,10%
	1,057,271		100%

Source: Statistik Austria , 2010a

The Austrian Statistical Office also carries out an analysis on the share of end use categories 'heating and cooling', 'steam generation', 'industrial furnaces', 'stationary engines', 'mobility, 'illumination and electronic data processing', 'electrochemical purposes' per energy carrier yielding a similar picture than the energy balance (Tab. 2).

The main share must be attributed to mobility (34.7%), heating and cooling (28.85%), industrial processes (23.65%), and mechanical work (stationary engines, appliances) (9.88%). What becomes apparent is the distribution of energy carriers over the different uses; while for heating and cooling a variety of energy carriers are available, transport depends almost exclusively on fossil fuels with 90% of energy coming from coal, oil, and gas. The import of oil, which accounts for 55% of total energy imports, is primarily responsible for the high import dependency of Austria (Rauh, 2006).

Tab. 2: Austrian energy balance 1970 to 2009. Final energy demand 2009.

2009 (values in TJ)	heating and cooling (incl. warm water)	steam generation	industrial furnaces	stationary engines	mobility	illumination and elect. data processing	electro-chemical purposes	sum
coal	3,386 TJ	3,136 TJ	13,612 TJ	0 TJ	8 TJ	0 TJ	0 TJ	20,143 TJ
	941 GWh	871 GWh	3,781 GWh	0 GWh	2 GWh	0 GWh	0 GWh	5,595 GWh
oil	61,773 TJ	2,626 TJ	9,896 TJ	16,126 TJ	324,492 TJ	0 TJ	0 TJ	414,913 TJ
	17,159GWh	729 GWh	2,749 GWh	4,479 GWh	90,137GWh	0 GWh	0 GWh	115,254 GWh
gas (including blast furnace gas, coke oven gas)	72,047 TJ	45,543 TJ	57,403 TJ	679 TJ	8,851 TJ	0 TJ	0 TJ	184,523 TJ
	20,013GWh	12,651GWh	15,945GWh	189 GWh	2,459 GWh	0 GWh	0 GWh	51,256 GWh
electricity	30,921 TJ	358 TJ	46,888 TJ	86,974 TJ	11,944 TJ	31,012 TJ	269 TJ	208,367 TJ
	8,589 GWh	99 GWh	13,024GWh	24,159GWh	3,318 GWh	8,614 GWh	75 GWh	57,880 GWh
district heating	55,962 TJ	205 TJ	7,381 TJ	0 TJ	0 TJ	0 TJ	0 TJ	63,549 TJ
	15,545GWh	57 GWh	2,050 GWh	0 GWh	0 GWh	0 GWh	0 GWh	17,653 GWh
firewood	54,666 TJ	1,442 TJ	6,663 TJ	0 TJ	0 TJ	0 TJ	0 TJ	62,772 TJ
	15,185 GWh	401 GWh	1,851 GWh	0 GWh	0 GWh	0 GWh	0 GWh	17,437 GWh
biogenic fuels (incl. fire peat, combustible waste)	17,543 TJ	36,252 TJ	16,909 TJ	678 TJ	21,432 TJ	0 TJ	0 TJ	92,813 TJ
	4,873 GWh	10,070GWh	4,697 GWh	188 GWh	5,953 GWh	0 GWh	0 GWh	25,781 GWh
ambient heat	8,758 TJ	0 TJ	1,434 TJ	0 TJ	0 TJ	0 TJ	0 TJ	10,192 TJ
	2,433 GWh	0 GWh	398 GWh	0 GWh	0 GWh	0 GWh	0 GWh	2,831 GWh
Sum	305,057 TJ	89,563 TJ	160,187 TJ	104,456 TJ	366,728 TJ	31,012 TJ	269 TJ	1,057,271 TJ
	84,738 GWh	24,878 GWh	44,496 GWh	29,016 GWh	101,869 GWh	8,614 GWh	75 GWh	293,686 GWh
%	28,85%	8,47%	15,15%	9,88%	34,69%	2,93%	0,03%	100,00%

Source: Statistik Austria, 2010b

3.1.1. Energy Use in Transportation

THE TRANSPORT SECTOR is regarded as one of the key consumers of energy and, hence, also one of the largest producers of greenhouse gas emissions. Furthermore, it is also the sector that sees by far the fastest growth in consumption, which increased by 71% between 1990 and 2009 (Statistik Austria, 2010a). Even more dramatic was the increase in air traffic by 140% between 1990 and 2008 (BMWFJ, 2010a). Nonetheless, air traffic still accounts for only 2.6% of total energy end use.
Reasons for this strong increase are manifold:

- the increase in car stock by 40% between 1979 and 2009,
- a general growing demand for personal mobility,
- a strong increase in freight traffic,
- a rebound effect as more cars/inhabitants result in more traffic,
- fuel export in vehicle tanks owing to the fact that mineral oil tax is considerably lower in Austria than in the neighbouring countries. Approximately 5% of fuel purchased in Austria is destined for consumption outside the country. However, the fuel exported in car tanks is included in the statistics and contributes to the Austrian energy balance (Pucher, 2010).

However, there are also critical voices that claim that when looking at the share of transportation in gross energy consumption, the contribution of road traffic is less dramatic. This is due to the fact that most statistics refer to final energy consumption which does not consider the – sometimes substantial – losses due to distribution and transformation. According to Pucher (2010), road traffic accounts for 15% of energy consumption when these effects are controlled for. He also shows that if the percentage of fuel (notably diesel for heavy duty vehicles) that is purchased in Austria, but consumed abroad is considered then the share of drops to 10%. However, Pucher does not account for losses in the energy chain that occur outside Austria.

Tab. 3: Gross energy consumption of transportation in absolute values and in percent of total primary energy consumption in 2009.

Transport mode	[values in PJ]	[values in GWh]	%
Heavy duty vehicles and buses	88	24,444	6.5 %
Passenger cars	134	37,222	9.9 %
Other traffic	46	12,778	3.4 %
Fuel export in vehicle tanks	69	19,167	5.1 %
Sum	337	93,611	24.9 %

Source: Pucher, 2010

3.1.2. Energy Use in Private Households

PRIVATE HOUSEHOLDS ARE another important factor in energy use and account for 24.68% of final energy consumption. Official statistics record the development of consumption for the categories 'heating and cooling' and 'other energy uses'[2].
Statistical data show two interesting facts:

[2] Austrian energy balance 1970 to 2009; microcensus energy use of households. Source: Statistic Austria (03.12.2010)

- heating and cooling is more than two times as energy intense as other energy uses (excluding energy demand for mobility),
- energy demand for heating is strongly dependent on annual temperatures.

Mild winters strongly influenced the development of consumption in the household sector which between 1990 and 2005 increase from 242,478 TJ to 282,859 TJ (67,355 GWh to 78,572 GWh) and then gradually decreased again to 260,932 TJ (72,481 GWh). Reasons for the increase are, among others, population growth of 8.6% since 1990, the increase in dwellings by 23% and the average increase in living area per person by 17% in the same period (BMWFJ, 2010a).
Interestingly, when controlled for annual average temperatures this increase is not confirmed. We can even observe a decreasing tendency when data are adjusted for the increase in average living space by relating energy consumption to m^2 floor space. This observation is also supported by the fact that population growth and increase in dwellings and in floor space per capita have contributed to the overall increasing energy demand in private households.

However, another conclusion can be drawn from statistical data: energy consumption per capita has been growing steadily since 1990.

Nevertheless, around 29% of final energy consumption in Austria can be related to heating and domestic hot water production (Statistik Austria, 2010b). For this reason, measures targeted at increasing energy efficiency places a lot of emphasis on these categories. Fossil fuels, such as oil (23.03%) and gas (25.65%), are the dominant energy carriers also in the sector 'heating/cooling and water heating'; however, alternatives exist and dependency on fossil fuels is less strong than in the transport sector. Renewables have a share of 22.3% and district heating has already a considerable reach of 21.01% (Tab. 4). If we further consider that 45% (~ 337,000 households) of district heating in Austria is generated from renewable energy sources than the use of renewables for heating and domestic hot water increases to one third (BMWFJ, 2010a).

Tab. 4: Energy use of households 2007/2008. Central heating without indication of fuel was defined as district heating.

Energy carrier	Number of households („main residence")	%
Wood, wood chips, wood pellets, wood briquettes	740,603	20.74%
Coal, coke, briquettes	37,030	1.04%
Heating oil, liquid gas	822,408	23.03%
Electricity	249,071	6.98%
Natural gas	916,024	25.65%
Solar heating, heat pumps	55,636	1.56%
District heating	750,117	21.01%
Sum	3.570.889	100.0%

Source: Statistik Austria, 2009a

3.1.3 Energy Intensity: A Measure of Energy Efficiency

AUSTRIAN GROSS INLAND energy consumption has increased continuously over the last decade, with few occasional interruptions due to economic development, oil price or climate conditions. It has almost doubled since 1970, from 796,846 TJ (221,346 GWh) in 1970 to 1,456,233 TJ (404,509 GWh) in 2005, when it reached a peak, and amounted to 1,353,964 (373,101 GWh) in 2009[3]. The main reason for the substantial decrease in 2008 and 2009 was the economic recession.

While consumption increased, gross domestic energy production in 2009 was at 482,875 TJ (134,132 GWh), while imports amounted to 1,201,175 TJ (333,660 GWh), which means that Austria imports ~80% of the energy demanded.

The import dependency of Austrian energy supply (net import tangent = imports-exports in % of gross inland consumption) amounts to the present total of 64.8 % and is well beyond the average of the EU-27 member states (~55%). In particular coal and oil have disproportionally high import quotas.

Tab. 5: Austrian energy balance 2009.

Energy balance 2009	[TJ]	[GWh]
gross inland production	482,875	134,132
imports	1,201,175	333,660
storage	-6,455	-1,793
exports	-323,632	-89,898
gross inland consumption	1,353,964	376,101
transformation input	860,263	238,962
transformation output	762,578	211,827
consumption of the energy sector	72,929	20,258
distribution losses + measuring differences	21,887	6,079
total losses	-192,501	-53,472
available for final consumption	1,161,463	322,628
final non-energy consumption	104,192	28,942
final energy consumption	1,057,271	293,686

Source: Statistik Austria, 2010a

Domestic production is characterised by

- high dependence on energy imports, in particular, fossil fuels due to the almost absence of own natural resources in the country apart from some minor oil extraction in the north-east of Austria which make up for 9% of national energy production,
- relatively large share of renewables in the Austrian energy mix.

Renewable account for 27.6% of the country's gross energy consumption which, compared to other European and Non-European countries, is significant. This is mainly due to the importance of hydropower (30% of energy production in 2009), but also due to the wide-spread exploitation of energy from renewable sources, such as wind power and biomass (43.3% of energy production in 2009).

[3] Austrian energy balance 1970 to 2009 structured according to useful energy analysis (NEA) 2005. Traffic is the sum of transportation and agricultural „off-road" traction. (Statistik Austria, 2010a)

As for hydropower, Austria and Sweden, discounting Switzerland and Norway as non-EU countries, have the largest share in the European Union. Regarding other renewables, such as solar energy or geothermal energy, the largest percentages in the EU can be found in Latvia, Finland, Sweden, Denmark, Austria, Portugal, Lithuania, and Estonia. Interestingly, outside the Union China is a leading consumer of renewable energy.

Renewables make up for 73.3%, thus, represent the lion's share of Austrian energy production. However, it is important to note that Austria is not energy sufficient and is only able to cover one third of its gross energy consumption, while the other two thirds have to be imported (BMWFJ, 2010a).

decoupling of energy consumption from economic growth

While in the long run, energy efficiency has increased markedly in Austria, gross energy consumption has risen nonetheless, diminishing the overall positive achievement. In other words, in the 1970s economic growth has surpassed energy consumption and the energy consumption relative to real GDP has declined ever since by ~32% between 1973 and today (BMWFJ, 2010a). This means that a relative decoupling of energy consumption from economic growth has taken place.

Regarding the energy efficiency of its economy, all established indicators show that Austria lies significantly below international and EU-wide average. The relationship between energy input and economic output of a national economy is called energy intensity.

energy intensity

It is the ratio between gross inland consumption of energy, as the sum of gross inland consumption of the five energy types 'coal', 'electricity', 'oil', 'natural gas' and 'renewable energy sources', and gross domestic product (GDP). The GDP figures are taken at constant prices to avoid the impact of inflation[4]. Energy intensity is expressed in kgoe[5]/1,000 Euro according to EUROSTAT or toe/1,000 USD according to OECD. For example, in 2006 Austria consumed 0.1590 million toe (tonnes of oil equivalent) per 1,000 USD GDP, while the OECD average was 0.1898 toe.

Another common indicator for international comparison is the gross domestic consumption per capita. With a figure of 3.99 toe per capita Austria ranges significantly below the OECD average of 4.64 toe, however, also above the EU-27 average of 3.55 toe. The comparison of EU countries shows that the wealth of countries expressed in GDP per capita is only partially reflected in its per capita consumption of energy. Countries like Sweden or the Netherlands, which have low toe per unit of GDP, have a high per capita consumption of toe (BMWFJ, 2010a).

3.1.4 Primary Energy Coefficients

MOST STATISTICS ON energy consumption do not make a clear distinction between primary energy, which refers to primary energy carriers recovered from nature (e.g., coal mined, gas extracted), and final energy, which is energy used to supply the final consumer with energy services (e.g., energy that comes out of the electric socket as we plug in an electrical devices). Presenting figures on final energy consumption without reference to the primary energy input needed to produce it masks the fact that it has undergone seve-

[4] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Energy_intensity

[5] kilogramme or tons of oil equivalent

ral steps from extraction, transformation, transmission, storage, and distribution and local conversion, all of which entail conversion losses.

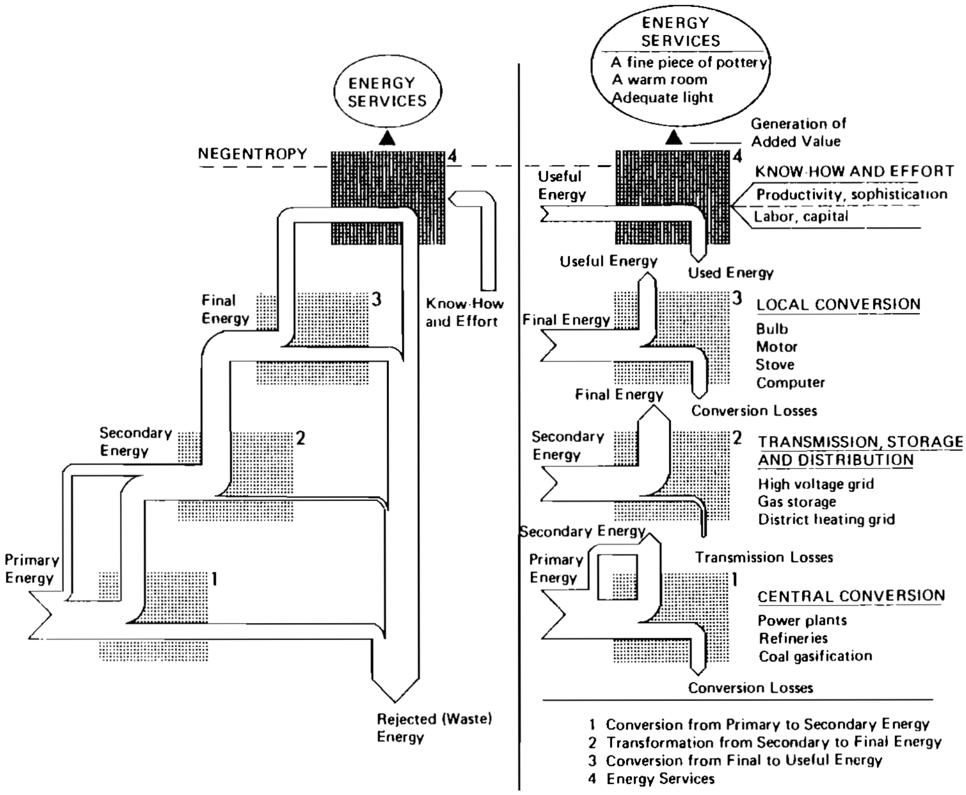

Fig. 2: Conversion from primary to final energy. (Anderer, Häfele, McDonald, Nakicenovic, et al., 1981)

primary energy

secondary energy

final energy

useful energy

Primary energy consumption refers to energy supply of crude energy to users prior to transformation, that is, energy that has not been subjected to any conversion or transformation process[6]. One of the few forms of primary energy that can be used as final energy is natural gas. Secondary energy is defined as an energy form that can be used over a broad spectrum of applications, such electricity and gasoline. The definition thus excludes energy used by the energy sector for conversion or for transmission. Naturally, there are several different ways to convert primary into secondary energy and different ways to transmit energy. Depending on how efficient these steps are[7] losses get bigger or smaller. Final energy consumption is the total energy consumed by end users, such as households, industry, and agriculture. It includes, for example, the energy that goes into a fuel tank in the form of gasoline. And, finally, useful energy is the energy actually stored in a product or used for a service (transformed into, e.g., mechanical work, heat, and light). Useful energy is closely linked to efficiency. The comparison of an electric engine and a combustion engine illustrates the difference between final and useful energy. For a car with an internal combustion engine conversion and transmission losses are about 6%; however, the efficiency of the engine is η=21-25% for a gasoline car and η=25-30% for a diesel car.

[6] Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997. (http://stats.oecd.org/glossary/detail.asp?ID=2112)

[7] For example, a CCGT power plant has an efficiency up to η=60% and a conventional coal-fired power plant an efficiency of up to η=40%

While in an electric drive vehicle conversion losses are ~44% for a CCGT power plant and transmission losses ~6%, the efficiency of the engine, however, is η=73%. Consequently, of 100% primary energy input ~23.7% can be exploited as useful energy in a vehicle with a combustion engine compared to ~38.4% if the same vehicle was to be propelled by an electric engine[8]. However, assuming a lower efficiency of electricity production of only η=30%, which after all is more realistic, can easily tip the balance in favour of the combustion engine.
The relationship between primary energy input and final energy output at the consumer is expressed by the primary energy coefficient:

$$f_P = \frac{Q_P}{Q_E} \tag{2.1}$$

f_P … primary energy coefficient
Q_P … input primary energy
Q_E … output final energy

Different primary energy coefficients for one and the same energy carrier can be found in studies (Frischknecht & Tuchschmid, 2008; Theissing & Theissing-Brauhart, 2009; Zach & Simander, 2010) and technical standards (e.g., DIN V 4701–10, ÖNORM EN 15603:2008, DIN 18599-100:2009) and it is difficult to tell which one is most accurate. Differences result from different data sources and different assumptions made regarding the energy overheads of delivery to point of use.

definition primary energy coefficient

According to EN 15603, generally included in the PEC should be "energy to extract the primary energy carrier; energy to transport the energy carrier from the production site to the utilization site; energy used for processing, storage, generation, transmission, distribution, and any other operations necessary for delivery to [the point of end use] (Austrian Standards Institute, 2008c)." Energy that may be optionally included is "energy to build the transformation units, energy to build the transportation system, and energy to clean up or dispose the wastes." In practice, energy overheads included in the calculation of PECs vary greatly, resulting in considerably different PECs. Also some PECs are based on the lower heating value, assuming that the latent heat of vaporization of water in the fuel and the reaction products is not recovered, while others are based on the upper heating value, taking into account the latent heat of vaporization of water in the combustion products, which can make considerable difference for energy carriers with a high content of H_2O such as wood or lignite.

PEC district heat

Another salient example of how different assumptions can lead to very different PECs is district heat. The calculation procedure is regulated in ÖNORM EN 15316-4-5 and follows the 'power bonus method', which means that "all energy inputs are related to the thermal output and the electricity produced is counted as a bonus" (Austrian Standards Institute, 2007b). Power bonus refers to the hypothetical electricity not being produced because of the additional exploitation of heat from electricity production. However, the

8 http://www.energyagency.at/fileadmin/aea/pdf/mobilitaet-verkehr/elkonf/Session_4_02_RAIMUND.pdf

saving effect depends very much on how the saved electricity would have been generated[9]. If the share of cogeneration in the production of district heat is high, as is the case with district heat in Vienna, than the assumptions that have to be made regarding the origin and mix of electricity considerably influence the result. The simplest approach (taken by Theissing & Theissing-Brauhart, 2009) is to assume that the heat substitutes a typical Austrian mix of fossil-fuelled electricity production. However, this approach is too simplistic as Austria has to import considerable amounts of electricity, especially in winter. However, the international trade of electricity since the liberalisation of the energy market makes the determination of the specific electricity mix of a country rather difficult. With respect to district heat, it is virtually impossible to determine, in retrospect, where the additional electricity would have come from. Zach and Simander (2010) calculated the PEC for Vienna district heat based on a substitution of the UCTE[10] electricity mix and a weighted mix of Austrian production and imported electricity from Germany and Czech Republic which are the two most important importing countries. The resulting non-renewable PEC is highest for the Austrian mix and lowest for the UCTE mix. The most realistic result (average for 2006-2008: 0.207) is obtained for the weighted mix of domestic production and importation. Differences originate mainly from the different share of nuclear energy which has a much higher primary energy demand. Other difficulties related to defining the primary energy factor for district heat (and also for electricity) is the fact that the mix of heat sources (heat and power cogeneration, waste incineration, process heat, biomass, peak load boiler) changes every year resulting in a different PEC for different periods of time and that results for one district heat provider are not transferable to another as the mix of heat sources is unique for each district heating system (Zach & Simander, 2010).

country differences

Needless to say that there are also considerable country differences in PECs. Especially regarding electrical power generation coefficients determined for other countries may not be uncritically adopted for Austria as the origin of the crude energy, transport routes, properties of the Austrian grid, and the particular Austrian energy mix have a strong influence. Furthermore, it is important to note that a distinction is made between total primary energy coefficient, including all energy overheads, and non-renewable primary energy coefficient, excluding the renewable energy component of primary energy, which may lead to a conversion factor less than unity for renewable energy sources. The two values may differ considerably and should not be intermingled. To illustrate the difference, for hydropower, most of the primary energy input is potential energy stored in the water flowing over a dam. Hence, the total PEC for electricity from a hydro power plant is 1.50 and the non-renewable PEC is 0.50 according to ÖNORM EN 15603 (Austrian Standards Institute, 2008c).

To conclude, determining PECs is rather complex and the size of a coefficient depends heavily on assumptions and definitions. Values from literature must not be uncritically adopted as they considerably influence the result of the energy assessment.

[9] A change in electricity demand does not equally affect all technologies for electricity production. Instead, most of the effect occurs in the technology or technologies providing the marginal production of electricity, such as caloric or nuclear power generation.

[10] UTCE: Union for the Co-ordination of Transmission of Electricity (now ENTSO-E) is an association comprised of 42 European Network of Transmission Systems Operators for (Continental) Europe that share an interconnected transmission grid in the EU.

Austrian primary energy coefficients

For Austria, no representative and commonly used primary energy coefficients have been published to the author's knowledge. PECs for several energy carriers with the purpose to calculate a representative PEC for district heating and district cooling according to ÖNORM EN 15316-4-5 were determined by Theissing and Theissing (2009). They are based on data from the ProBas-database provided by the German Environmental Agency, data from the Swiss lifecycle database Ecoinvent and data from the Austrian Statistical Office and from Energy-Control Austria. Both databases contain data on energy demand for extraction, transport, and processing for different energy carriers, however, Ecoinvent data are based on the upper heating value. Data on gas storage and conversion efficiencies in electricity production were retrieved from the Austrian energy balance, which is compiled by the Austrian Statistical Office, and data on primary gas input and on conversion efficiencies were taken from the Austrian gas balances and the monthly electricity balances, which are recorded by Energy Control Austria.

Useful primary energy coefficients which will be used throughout the paper are presented Tab. 51 in Annex I. All values refer to non-renewable PECs and were determined for 2009 (resp. 2008).

3.2 Energy Efficiency in Legislation

ENERGY CONSUMPTION in Austria and in the European Union follows a similar pattern, which means: high import dependency and limited domestic fossil resources. The increasing dependence on energy imports and rising energy prices risk jeopardising security and competitiveness. Therefore, the security of energy supply is high on the Union's agenda and several community initiatives and directives have been adopted to counteract Europe's import dependency. In view of the threat of global climate change and with the expectation that requirements for higher energy efficiency and increased use of renewables will stimulate development in green technology and, hence, consolidate and expand Europe's technological leadership, the EU has adopted some highly ambitious pieces of legislation.

3.2.1 The 20-20-20 Initiative of the European Union

IN DECEMBER 2008 the 20-20-20 by 2020 strategy was passed by the European Parliament, which so far is the most far-reaching initiative of the EU in the field of energy. The legal foundation of the initiative is Article 194 of the Treaty of Lisbon which lays down that the Union policy on energy shall aim to "ensure the functioning of the energy market, ensure security of energy supply in the Union, promote energy efficiency and energy saving and the development of new and renewable forms of energy, and promote the interconnection of energy networks."

The Union has set itself the goal to saving 20% of its primary energy consumption compared to projections, to reduce greenhouse gases by 20% and to increase the share of renewable energy to 20%. Energy efficiency is at the heart of the strategy, as it is one of the most cost effective ways to enhance security of energy supply, to reduce emissions of greenhouse gases and other pollutants, and to keep energy costs low. EU energy efficiency legislation covers the energy performance of buildings (Directive 2010/31/EU which repeals Directive 2002/91/EC), energy end-use efficiency and energy services

(Directive 2006/32/EC), cogeneration (Directive 2004/8/EC), and the energy efficiency of products (e.g., Directive 2005/32/EC, Directive 2010/30/EU, Commission Regulation (EC) No 245/2009, Council Decision 2006/1005/EC). On a more specific note, the energy efficiency of products includes labelling of product categories, such as tyres or office equipment, and minimum efficiency standards for the design of energy-using appliances, such as lamps and hot water boilers. Furthermore, in 2011 the European Commission released a proposal for a directive on energy efficiency that shall oblige public bodies, energy utilities, the industry, and consumers to better manage their energy consumption.

The most relevant EU legislation on energy efficiency in the context this thesis is the Directive on the energy performance of buildings, which shall be discussed in more detail.

3.2.2 Directive on the Energy Performance of Buildings – Energy Performance Certificate

AS PART OF the Community initiatives on climate change and security of supply, the European Parliament and the Council adopted in 2002 the Directive 2002/91/EC on the energy performance of buildings[11]. In 2010 a recast of the directive (Directive 2010/31/EU) was adopted in order to strengthen the energy performance requirements and to streamline some of its provisions. Amendments concern specifications of requirements regarding the common general methodological framework and the application of minimum requirements. One example is the 1000 m^2 threshold for defining minimum requirements for the renovation of existing buildings which was eliminated. Additionally, minimum energy performance requirements must now be set by the member states for technical building systems (e.g., large ventilation systems, air conditioning, heating, etc.) and for the renovation of building elements (e.g., roof, façade, etc.). Newly introduced was also the benchmarking methodology framework for calculating cost-optimal levels of minimum requirements, meaning minimised lifecycle costs, which shall help member states set their requirements at a cost-optimal level. Furthermore, the use of energy performance indicators in advertisements is to become mandatory.

Main focus of the Directive is on:

- developing a common methodology for the calculation of the integrated energy performance of buildings. The method should include all the aspects which determine energy efficiency, including the quality of the building's insulation, heating and cooling installations, lighting installations, the position and orientation of the building, heat recovery, etc. A very general framework for the calculation of energy performance is contained in the Annex of the Directive, which specifies which aspects to include in the assessment, how to classify buildings, and which energy producing installations to account for in the calculation.
- defining minimum energy performance requirements for new buildings and existing buildings that are subject to major renovation based on the above method. The member states are responsible for drawing up the standards and for ensuring the implementation of certifications and inspections.

[11] information retrieved from: http://europa.eu/legislation_summaries/other/l27042_en.htm [Accessed on: 26/08/11]

Overview of the most relevant Austrian and European standards						
	Residential building	Non-residential building	National		European	
Energy performance certificate	✓	✓	ÖNORM H 5055	ÖNORM EN 15217		
Requirements on energy efficiency	✓	✓	ÖNORM H 5055	prEN 15603		
Reference conditions (climate, user profiles)	✓	✓	ÖNORM B 8110-5	–		
			Building construction	Technical building systems	Building construction	Technical building systems
Space heating demand	✓	✓	ÖNORM B 8110-6		ÖNORM EN ISO 13790	
Space cooling demand		✓	ÖNORM B 8110-6		ÖNORM EN ISO 13790	
Energy demand heating system	✓	✓		ÖNORM H 5056		ÖNORM EN 15316
Energy demand ventilation system		✓		ÖNORM H 5057		ÖNORM EN 13779
Energy demand air conditioning		✓		ÖNORM H 5058		ÖNORM EN 13779
Energy demand lightning		✓		ÖNORM H 5059		ÖNORM EN 15193-1

Source: Austrian Standards Institute, 2008e

Tab. 6: Overview of the most relevant Austrian standards and their European equivalents.

- implementing a mandatory certification of the energy performance of residential and non-residential buildings. The certification must be such as to make a comparison of energy efficiency of buildings possible, by relating its energy demand to defined energy performance requirements and efficiency classes, and it has to propose a set of cost-efficient measures for improving efficiency.
- defining regular inspections of boilers and central air-conditioning systems in buildings and the assessment of heating installations with boilers >15 years old.

While the Directive addresses the residential sector and the tertiary sector (offices, public buildings, etc.), the scope of the provisions on certification does not, however, include special buildings, such as historic buildings, industrial sites, etc.

In Austria, the Directive was transposed into national law by adopting the *"Energieausweis-Vorlage-Gesetz – EAVG"* in 2006. It regulates the duty of the seller or renter, as part of civil law, to provide an energy performance certificate not older than 10 years.
Since building laws and regulations, housing construction subsidy acts as well as laws regarding power generation are part of provincial legislation, the actual implementation of the energy performance certificate lies with the jurisdiction of the Bundesländer. Therefore, regulations about the calculation method, content and form of the certification, energy performance requirements of different building classes, as well as the appointment of accredited, independent experts is not applied uniformly by the provinces. However, eight of the nine provinces agreed on a largely standardized calculation method, while Salzburg has just recently harmonised its regulation so that standards are now, by and large, the same throughout Austria.

OIB guideline 6

The basis for implementation of the energy performance indicators in the corresponding building laws is the OIB-guideline 6 on "Energy saving and heat insulation" (Österreichisches Institut für Bautechnik, 2007b) together with the corresponding handbook on "Energy-related behaviour of buildings" (Österreichisches Institut für Bautechnik, 2007a), which was drawn up by an expert team from all provinces aiming at harmonising the relevant technical standards. The OIB-guideline defines minimum standards for total energy efficiency of residential and non-residential buildings, minimum requirements for individual building elements and technical building systems, and it contains a template of the energy performance certificate of buildings to be issued (*Energieausweis*). The calculation method itself is described in the OIB-handbook, which contains also instructions for a simplified calculation of the energy performance of existing buildings, and in the corresponding ÖNORM standards. Simplified assumption can be made regarding the geometry of buildings, construction physics, more specifically the heat transmittance of different building elements, and technical building services (e.g., heating, ventilation, air conditioning and refrigeration). For heat transmittance default values derived from the building regulations of the individual *Bundesländer* may replace actual input values in the calculation. The calculation manual is, in principal, based on and in conformity with the ISO standard EN ISO 13790 (Austrian Standards Institute, 2008d) for the net calculation of energy use for space heating and cooling of buildings and EN 15316, EN 13779 and EN 15193-1 for the calculation of energy use for technical building systems.

The major part of the OIB guideline was transposed into six Austrian ÖNORM-standards according to the different final energy and useful energy demands of a building, while the energy performance certificate itself is regulated in the standard ÖNORM H 5055. However, it is up to each *Bundesland* to declare the guideline and corresponding norms as legally binding (Bacher, 2010). Furthermore, most provinces introduced energy efficiency minimum requirements in the housing construction subsidy acts which have to be fulfilled in order to receive subsidies for new housing construction. In some provinces, e.g., Salzburg, this financial support is even staggered accorded to energy efficiency classes.

The main energy performance indicator in the certificate is the energy efficiency indicator. All *Bundesländer*, except for Salzburg, use as indicator the heating demand Q_H in kWh per square meter gross conditioned floor space and year for the defined reference climate. The heating demand is the energy that needs to be supplied to maintain a fixed set-point room temperature. Salzburg is the only province to have introduced the LEK-value as energy efficiency indicator, a parameter for the thermal insulating quality of the thermal envelope of the building considering the geometry of the building. The energy performance of a building is classified into 9 energy efficiency classes, from A++ to G, according to the standard ÖNORM H 5055 (Austrian Standards Institute, 2008e).

Tab. 7: Energy efficiency classes defined in ÖNORM H 5055.

(a) values are reference values; the technical building regulations 2008 re-adjust limit values by allowing more flexible energy classes depending on the building geometry and size

(b) related to a single family house; four-person household with 150 m² floor space (excluding hot water demand)

Energy efficiency classes according to ÖNORM H 5055			
Q_H [kWh/(m²a)] [a]	Energy classes		Q_H [l oilequiv.][b]
≤ 10	A++	Passive house standard, *Passivhaus*	200–300
≤ 15	A+	Very low energy house, *Niedrigstenergiehaus*	400–700
≤ 25	A		
≤ 50	B	Low energy house, *Niedrigenergiehaus*	1000–1500
≤ 100	C	Standard according to building regulations	1500–2500 [a]
≤ 150	D	Old buildings without thermal renovation	> 3000 [a]
≤ 200	E		
≤ 250	F		
> 250	G		

Source: Austrian Standards Institute, 2008d; http://de.wikipedia.org/wiki/Energiestandard#.C3.96sterreich [accessed on 22 November 2011]

Standards for newly constructed buildings or thermal rehabilitation regarding heating demand, hot water demand and energy demand for technical building services as well as requirements for heat transmitting building elements and technical building systems are defined in the OIB-guideline 6 on "Energy saving and heat insulation" (Österreichisches Institut für Bautechnik, 2007b). The compliance with the maximum permissible heating demand Q_H for newly constructed residential buildings or thermal rehabilitation of residential buildings in kWh per square meter gross conditioned floor space and year and depending on the building geometry, expressed by the characteristic length ℓ_c (cf. formula 4.9), and the reference climate, according to ÖNORM H 5055, can be determined according to the following formulas:

$$Q_H = 19 \cdot (1 + 2.5/\ell_c) \text{ in kWh/(m}^2\text{a) for newly constructed residential buildings} \quad (2.2)$$

$$Q_H = 25 \cdot (1 + 2.5/\ell_c) \text{ in kWh/(m}^2\text{a) for residential buildings subject to major renovations} \quad (2.3)$$

Since 1.1.2010 the maximum permissible heating demand Q_H is 66.5 kWh/(m²a) corresponding to energy class C.

3.2.3 Austrian Energy Strategy

THE "ENERGY 2020 STRATEGY", as part of the climate and energy package of the European Union, provides a European framework for energy policy and defines the energy priorities for the coming 10 years. Most of the activities for implementation the strategy are, however, set on a national level. Current Austrian energy policy is therefore, in fact, mainly a European energy policy which sets clear targets and leaves it to the member states to develop action plans on how to implement them. In June 2010 all member states had to report to the Commission on how they are planning to achieve goals on the national level.

target value 1,100 PJ (305,556 GWh)

In detail, for Austria, it contains the obligation to increase the share of renewables in the overall energy consumption from 24% to 34% by 2020, to increase energy efficiency by 20% and to cut greenhouse gas emissions by 16% (those emissions which are not included in the emissions trading scheme) relative to the base year 2005 (BMWFJ, 2010b). Translated into absolute numbers, the 20% energy efficiency goal means that energy consumption has to be stabilized on the level of the base year 2005 by 2020, thus, reaching a target value of 1,100 PJ (305,556 GWh) for the overall consumption per year. In order to monitor the implementation of the 20-20-20 strategy, national governments were required to report back to the commission how they are intending to achieve these goals. Details on the implementation of the 20-20-20 Initiative were laid down in the Austrian National Energy Strategy Paper, which is the result of this formal requirement and was presented to the public and submitted to the EU Commission in June 2010.

Austrian National Energy Strategy

The Austrian National Energy Strategy (2010b) has been elaborated in a unique participatory process between stakeholders at the various governmental levels, from industry, from NGOs and other interest groups and experts from science and other private and public institutions. The involvement of stakeholders with very diverging views was meant to warrant the general acceptability of measures and the interdisciplinary working groups produced over 370 proposed measures.

On the strategic level, the implementation of measures shall build on a better embedding of energy and climate goals in spatial planning, reinitiate the discussion on an ecological fiscal reform and on the screening of subsidies and funding instruments as for their environmental effectiveness, and shall build on the promotion of efforts in research, technology, and innovation.

national action plans

On the implementation level, so-called national action plans were adopted for each "pillar" of the 20-20-20 strategy: Renewable energy, energy efficiency and CO_2 emissions reduction. Regarding the reduction of energy consumption for the sector "buildings", the action plan includes a targeted quota for building rehabilitations, such as thermal optimisation of building carcasses, renovation of heating systems and improvements of energy use in office buildings, of 3% per year. In the area of "production, services and small-scale consumption" a reduction shall be achieved by encouraging energy management systems, energy consulting, and procurement that targets at energy-efficient goods. The third focus is on "mobility" and, here, the action plan proposes the reduction of traffic emissions through the use of renewable energy sources, the expansion of public transport and freight transport by rail, and the fostering of vehicle electric drive systems. The action plans are further broken down into a catalogue of measures.

3.2.3.1 Renewables

The expansion of renewable energy is immensely important for strengthening national energy self-sufficiency and the security of supply but is also expected to create employment, improve competitiveness, and is furthermore indispensable for achieving the energy and climate goals.

Key points of the strategy are:
- the use and exploitation of potentials in the area of hydropower, wind power, biomass and photo-voltaics;
- the expansion of decentralised solutions for heating that are tailored to the regional strengths; such solutions could be, for example, district heating in urban areas or individual solutions (solar thermal systems, biomass, ambient heat) in rural areas; in the longer run fossil fuels shall be completely replaced by renewables in heating;
- the compliance with the EU directive on biofuels in the area of traffic and the improvement of electric vehicle networks such as the provision of publicly-accessible charging stations and battery swap stations.

Relevant renewable sources of energy for Austria are hydropower, wind- and solar energy, ambient heat, biomass as well as biogas such as sewage and landfill gas. In the area of renewable electricity, the plan is to expand hydropower by 12.6 PJ (3,500 GWh) by the year 2015 and double the rate of wind power. Furthermore, the rate at which buildings are equipped with photo-voltaics shall be accelerated.
Some of these renewable energy technologies, such as wind power, photo-voltaics, and biogenic energy sources, are still rather at an infant stage and need to be further developed in order to be profitable and will therefore continue to be subsidised (BMWFJ, 2010b).

The 34% goal is split up as follows:
- hydropower: 41.2%
- wind power: 4.5%
- photovoltaic: 0,3%
- biogenous energy sources (biomass, biogas): 51%

3.2.3.2 Energy Efficiency

The Austrian National Energy Strategy (2010b) recognizes that energy efficiency is the key to Austrian energy policy and that so far the discussion was too much centred on the supply side and too little focused on energy efficiency potentials on the demand side.

The priorities chosen in the field of energy efficiency are:
- buildings: reduce the need for cooling or heating through improved building standards towards “almost zero energy buildings”, a technology that substantially reduces heat loss in buildings; energy saving potential: – 12%
- energy consumption of households and businesses: reduce the consumption of electricity and increase waste heat utilisation, for instance waste heat from industrial cooling systems, which shall be facilitated by means of energy consulting and the introduction of energy management systems in companies; energy saving potential for electricity: – 6%
- efficient mobility: promote the use of alternative drive systems (that run with fuel cells and alternative fuels) and e-mobility; provide offers for means of transportation other than private motor vehicles (walking, cycling, public transport); energy saving potential: – 22%

▸ efficient use of primary energy and waste heat: for companies using energy-intensive manufacturing processes, in energy industry as well as in households and businesses (BMWFJ, 2010b)

Experts claim that the potential for improving energy efficiency with currently existing technologies and economic measures is in either case sufficient to fulfil the efficiency targets of the EU.

Tab. 8: Efficiency increase by sector according to the National Energy Strategy.

GOALS BY SECTORS				
		2005	Goals	2020
		PJ (GWh)	%	PJ (GWh)
Buildings	Heating, cooling, residential-, office- and commercial buildings	337 (93,611)	– 10 %	303 (84,167)
Households, businesses, services, agriculture, small-scale energy consumption	Without heating and off-road traffic	206 (57,222)	+10 %	227 (63,056)
Energy-intense manufacturing	Includes the sectors iron & steel production, chemical industry, non-ferrous metals, glass production, stone & earth sector, paper and printing industry, wood industry (heating excluded)	178 (49,444)	+15 %	205 (56,944)
Mobility	including off-road vehicles	385 (106,944)	– 5 %	366 (101, 667)
		1,106 (307,222)		1,100 (307,222)

Source: BMWFJ, 2010b

3.2.3.3 Measures Targeted at Land Use Policy and Traffic Management

To achieve the envisaged reduction in energy use and green house gas emissions, every effort has to be undertaken to increase energy efficiency and spatial planning can play an important role in tapping the full potential of energy saving.
This fact was also acknowledged by the Austrian National Energy Strategy by proposing a series of measures targeted at land use planning and traffic and mobility management (BMWFJ, 2010b).

Increased energy efficiency has to be achieved in the following key areas:
▸ buildings – reduction of need for heating and cooling;
▸ energy consumption of households and companies – focus on electricity consumption and waste heat utilisation;
▸ efficient mobility.

Tab. 9: Land use policy and traffic management related measures proposed in the Austrian National Energy Strategy.

PACKAGE OF MEASURES	
Land use policy and traffic management (*Energieraumplanung*)	Promoting compact settlements and mixed land use
	Revision of existing traffic and spatial planning policies
	"Further development" of § 15a B-VG agreement between federal state and federal countries (legislation and enforcement)
Buildings	Earmarking of existing taxes and subsidies
	Promoting thermal rehabilitation of buildings, the use of renewable energies for heating and cooling
	New constructions and building alterations: obligation to install solar thermal systems; obligation to comply with CO_2 emission limit values
	Promoting technical innovation
Mobility	Measures targeted at vehicles, fuels and propulsion systems
	Promotion and expansion of public transportation
	Mobility management, traffic management
	Adaptation of levies and taxis (mineral oil tax, road pricing)

Source: BMWFJ, 2010b

3.3 Energy and Spatial Planning

land consumption

IN AUSTRIA, there is a longstanding tradition of scholarly criticism on the prevailing spatial planning practices that encourage a careless and wasteful use of the resource "land". Land consumption is increasing continuously and amounted to 14 hectares of land consumed in average for settlement and transport activities every day in 2009[12]. In view of Austria's topography, considering that only 37% of the state territory is usable as "permanent settlement area", this is far beyond what can be considered sustainable. It leads to a permanent loss of arable land and natural environments as building activities takes place mostly in areas which are also suitable for competing land uses such as agriculture, forestry, nature conservation, and leisure. Land consumption also conflicts with intentions to increase the use of renewable energy carriers (e.g., wind power, photovoltaic) in the future, as renewable energy production generally requires larger areas for producing the same amount of energy as a comparable caloric power plant (ÖROK, 2009).

Environmental impacts of land consumption are related to the loss and fragmentation of habitats due to the construction of building traffic infrastructure, the pressure on nature areas and biodiversity, and the detrimental effect of land sealing on soil which may lead to land degradation. Overdevelopment of rural areas and urban sprawl has also significant economic impacts such as additional costs for technical infrastructure and technical facilities and social infrastructure associated with less compact developments (Doubek & Zanetti, 1999; Doubek & Hiebl, 2001). By the same token, the pattern of unsustainable land consumption of the past decades has produced adverse effects associated with increasing volume of traffic that have direct impacts on the quality of life and human health, such as poor air quality and high noise levels. More recently, the focus of the debate is on land consuming spatial planning practices since they are associated with higher energy demand for mobility, housing and public services.

[12] Austrian Environmental Agency

Much of the negative spin-offs in spatial development in Austria, such as urban sprawl, rural overdevelopment, suburbanization, increasing traffic load, and depopulation of the village centres, can be related to, on the one hand, existing institutional structures and the distribution of competences. Public authorities fail to control the municipalities that have considerable autonomy in decision making in spatial planning, in drawing up local zoning plans and in giving out building permits. On the other hand, they can be associated with taxes and subsidies, which provide the wrong incentives and therefore exacerbate the problems created by demography and changing living habits (Seiß, 2006).
Basic understanding of Austrian spatial planning legislation and the fiscal system is essential for being able to suggest improvements to the current situations.

3.3.1 Spatial Planning Practises in Austria

Austria is a federation of nine states, including Vienna, with political representation and policy-making taking place on the three levels: *Bund* (federal government), *Land* (federal state) and *Gemeinde* (municipality). This also applies to spatial planning, which has to be performed in coordination with all three levels. The distribution of powers in spatial planning has been laid down by the Austrian Constitutional Court in 1954 and has the rank of constitutional law:

- comprehensive (or physical) spatial planning in legislation and execution is the autonomous responsibility of the federal states;
- important sectoral planning (for example, railways, the supra-regional road network, forestry, and laws relating to water) remains express power of the federal government;
- local spatial planning is the autonomous sphere of competence of the municipalities.

No planning authority exists on the regional scale, although regional development plans (*Regionale Raumordnungsprogramme*) are drawn up. However, they often either lay down conflicting guidelines and/or are not enforceable because the responsible institution (e.g., a ministry) is not bound by them. The consequence, in practice, is that the federal government and the states both carry out parallel activities related to spatial planning. In spite of the formal competence for comprehensive spatial planning of the states, these must rely on the cooperation of the federal government because several federal ministries have powers over important areas which are relevant to spatial planning.

3.3.1.1 Spatial Planning Instruments

Several spatial planning instruments exist which, by and large, can be found in all nine federal states despite some differences, which will not be addressed here.

Federal Government

On the level of the federal government: No federal law on spatial planning exists. In order to enhance cooperation in spatial planning policy the Austrian Conference on Regional Planning (*ÖROK*), bringing together the federal government, the provinces, and local communities, was created. However, cooperation is on a voluntary basis and a ten-year Austrian Regional Planning Concept, which is drawn up by the ÖROK, is not a binding planning instrument.

Federal States

On the level of the federal states: At this level spatial planning laws (*Raumordnungsgesetze*) are passed and based on them development plans (state and regional level) and sectoral plans (state and regional level) are implemented. States also have the duty to supervise communal planning and to assist municipalities in their work, i.e., they approve the conformity of zoning plans and building regulation plans at the municipal level with the spatial planning laws as well as with, e.g., the state or regional development plans. After approval these instruments then become binding for the municipal building authority and land owners.

municipalities

On the level of municipalities: Municipalities control permissible land use through the *Flächenwidmungsplan* (zoning plan) and draw up a *Bebauungsplan* (building regulation plan) that determines the use of building land. The zoning plan determines the possible use of properties for the entire territory of the municipality, which is divided into different land use categories, mainly into building land, transportation zones, and green land. The zoning plan should be reviewed every 5 to 10 years. The implementation of these plans is accomplished by building permit proceedings.

3.3.1.2 Shortcomings of Present Spatial Planning System

The current system has several shortcomings which aggravate the problems of increasing land consumption and the spread of low-density settlements.

Flexible Application of Zoning Plans

By law, zoning plans should be reviewed and adopted every 5 to 10 years, even though the durations vary from state to state. However, the statutory time limits for redrafting the entire plan are mostly exceeded while practice has been to make continuous modifications regarding locations in order to be able to realize certain projects which all too often receive consent despite contradicting the zoning plan. In this sense, the zoning plans are often not so much an instrument for controlling development but rather a cartographic record of the current status of building land zoning. However, according to Schindegger and Winkler (2000) several decisions of the administrative court indicate that in the future, planning will be much better founded in content and fewer modifications to plans will be possible.

Deficient Distribution of Competences

There can be said to be a power vacuum in spatial planning on the regional scale, a scale which is hardly addressed in the existing planning instruments, and on the level of the federal government, which has no supervisory power over the states. It has, however, competences in policy areas, such as traffic, water, forestry, etc., which have significant territorial implications. Parallel and contradictory planning is therefore unavoidable.

Schindegger and Winkler (2000) argue that "in a country organized as a federation which has such a fragmented and sensitive power structure it would in practice only be possible to make changes to the distribution of competence based on a political consensus at all levels. For this reason it is improbable that great changes will occur even if the distribution of competence is deficient from a political and legal point of view, and the efficiency of spatial planning is hindered." Several attempts in the past to iron out the competence situation and to achieve closer cooperation among the three levels in the area of spatial planning have failed and existing cooperation is based on a voluntary political agreement.

Lack of Coherence

Spatial plans set at the federal state level are often not fully co-ordinated with detailed planning and zoning decisions taken at the municipal level, particularly as regards nature conservation, flood protection and transport. Nature and landscape conservation have a long tradition in Austria and are, just like spatial planning, competences of the federal states, while other legislation, which is relevant for environmental issues, is competence of the federal government. Therefore, environmental legislation remains complex and dispersed in numerous federal and provincial laws and ordinances. Although the introduction of a national environment plan and strategy was a significant first step in national-level environmental planning and was catalytic in solidifying socio-political consensus on environmental objectives, its implementation and monitoring were not always pursued (OECD, 2003). Different strategies are also inherently contradictory, which is generally a problem in spatial planning as many land uses compete with each other.

Lack of Cooperation

Inter-communal and inter-regional cooperation in spatial planning matters is not the custom, leading to a situation in which no spatial planning on a supra-local and a regional level exists for large parts of the country's territory. This failure to cooperate, in particular between municipalities, is one of the main reasons for the expansive development patterns that we find all over the country. Municipalities aim to attract new residents and enterprises as the fiscal system rewards municipalities which grow in number of enterprises and inhabitants. Due to their extensive autonomy in giving out building permits, the municipalities are in competition with each other rather than seeing each other as partners.

For this reason, locations of trade and industrial enterprises are widely dispersed throughout the entire country and there is hardly any municipality which does not zone for industrial areas because their high dependency on the income from local businesses has turned them into competitors in the market for businesses willing to (re)locate. Because of this dependence, the question of industrial area zoning is often driven by the location preferences of enterprises. According to Schindegger and Winkler (2000) "very often enterprises looking for a new location negotiate the land purchase, and thus, the location, first with the property owner, and then both together contact the municipality to request re-zoning from green land to commercial industrial building areas."

Considerable Discretion of Municipalities

Municipalities have a very strong position in Austrian spatial planning. On the one hand, they have a high degree of financial responsibility and, on the other hand, they have considerable scope for implementing autonomous policies for spatial development. Schindegger and Winkler (2000) conclude that "in Austria the development of spatial structures […] is decided in practice primarily by the municipalities". It has often been criticized (e.g., Seiß, 2006; Fassmann, etc.) that mayors, in virtue of their power to give out building permits and given that their function is a political one, may be subject to pressure to do favours and to give in to desires of local interest groups or individuals who increase their own welfare to the detriment of everybody else's welfare. After all, zoning plans, despite having binding character, are often amended and a change in land use classification in the zoning plan can increase the value of property by up to 100% (Seiß, 2006).

Building Land may be Subject to Speculation
Practice until now has been to only grant the right to build when defining building land in the zoning plan, but not to prescribe any further obligations to actually implement the use it is zoned for. This has led to the situation that land owners wait until they can sell their land at great profits at a later date in expectation of an increase in value, e.g., due to infrastructure development around the land location. In this manner, the partial availability of building land area leads to renewed demand for more building land. In many municipalities with high development pressure a paradoxical situation has occurred: large reserves of unused building land exist and at the same time properties are not readily available for construction.

Several attempts of legal reforms have been made to avoid having building land remain unused:
- fee for unused building land that becomes due after a certain period of time expires;
- contingency of building land zoning with a private law contract between municipality and land owner in which the land owner enters the obligation to build on the land within a certain time limit.

3.3.2 Contribution of Land Use to Energy Demand

IN RECENT YEARS, the focus of the discussion on land use planning has somewhat shifted away from direct environmental impacts and from the cost aspect to the impact of spatial planning on energy consumption and, hence, CO_2 emissions.
Undeniably, the way we structure our activities in space has implications on our energy consumption. This concerns in particular traffic and household related energy consumption patterns which are strongly shaped by land use (planning):
- demand for mobility (centralized vs. decentralized approach; mixed land use vs. mono-functional land use);
- urban density (compact cities vs. low density, discontinuous development);
- supply structures of goods and services (centralized, decentralized networks);
- technological efficiency (building regulations and building standards).

3.3.2.1 Literature Review

While the relationship between land use planning and energy consumption seems to be quite common-sensical, a study of recent scientific literature shows that research is still fragmentary and split into sub-areas of research. Generally, most studies can be subsumed to two different fields of interest: one on inventorying and comparing urban energy consumption and the other one on the implication of urban density on transportation.
Studies concerned with quantifying the energy consumption of cities and/or metropolitan areas generally fall into two broad categories:

- those that inventory local emissions to directly support local policy objectives, e.g., energy policy and climate and sustainability initiatives of cities;
- those that investigate in the relationship between energy use and patterns of urban development.

For many of these studies the ultimate goal is to quantify carbon emissions.

A second observation that can be made is that most studies focus on "urban" environments rather than on "rural" areas. This is not surprising given that cities are assumed to play a central role in shaping global energy demand and given the growing urban leadership on climate change mitigation, which is particularly true on the global level. The International Energy Agency found that, globally, urban areas account for 67% of energy consumption and 71% of CO_2 emissions (International Energy Agency (IEA), 2008). However, aggregated consumption tells us little about the per capita consumption of a city's population, which is necessary if we want to compare different cities or different urban patterns to gain insights about the impact of land use planning on energy demand. While the per capita consumption in cities tends to be smaller than national average in industrialised countries (Glaeser & Kahn, 2010; Parshall et al., 2010), which is also true for Austria (Bohunovsky, Grünberger, Frühmann & Hinterberger, 2010), this relationship shows inverse characteristics in developing countries (Parikh & Shukla, 1995; Moomaw & Shatter, 1996; Lebel et al., 2007). Lebel et al. (2007) conclude that urban centres in the developing world may have higher emissions than smaller cities or rural areas because these urban locations are placing more emphasis on private vehicle use and ownership, are more prone to sprawling growth, experience changes in family structure moving towards smaller family sizes in larger dwelling spaces, witness a shift towards more protein-rich and energy-intensive diets, and undergo massive increases in standards of living, purchasing power, and consumption of goods and services.

Therefore a basic distinction has to be made between studies concerned with energy consumption in developed countries and studies focusing on developing countries. These findings also throw into question the assumed positive correlation between per capita income, which is generally higher in cities, and energy consumption. While it has been demonstrated that higher income is one of the most significant indicators of higher energy use, this conclusion is not consistent with results from developed countries. However, it is important here to not confuse correlation with causality (cf. Vance & Hedel, 2007). Sovacool and Brown (2010) conclude that the record on carbon-efficiency of metropolitan areas and cities is complicated; depending on how they are designed and on the behaviour of their inhabitants, cities and metropolitan areas can be both a key contributor to climate change and a key factor in mitigating it.
Consequently, a summary of the various approaches will be presented.

3.3.2.2 Methodological Approaches

A variety of approaches and estimates can be found in studies on urban energy consumption which makes comparison of results difficult. Methodological differences are related to:

Different Quantitative Research Methods

regression models

The majority of cross-sectional studies develop regression models that relate energy consumption to physical, economic, and social aspects of the urban environment. One such study is that of Parshall et al. (2010). They combine an exploration of different urban/rural classification systems with an evaluation of the ability of the "Vulcan" data product, originally conceived of as a high-resolution inventory of fossil-based sources of carbon with scientific applications in carbon cycle modelling, to measure local energy use for the USA.

lifecycle analysis

However, some take a more holistic and consistent methodology to account for 'grey energy', energy embodied in the whole process from the production to the disposal of a product or service, by means of a lifecycle analysis. Ramaswami et al. (2008) conduct greenhouse gas inventories for US cities viewing the city as a demand centre for both energy and key urban materials by incorporating spatial allocation of surface and airline travel across collocated cities in larger metropolitan regions and incorporating life-cycle assessment to quantify the embodied energy of key urban materials (food, water, fuel, and concrete). They first apply their method to the City and County of Denver and found that the estimated embodied energy of transportation fuels and food contribute more than 15% of the inventory, while the embodied energy of urban cement use alone contributes in the order of 2%. In the following step, they used the same hybrid lifecycle-based approach to 8 US cities and found that cross-boundary activities contribute on average 47% more than the in-boundary GHG contributions traditionally reported for cities, indicating significant truncation at city boundaries of GHG emissions associated with urban activities.

Different Dependent Variables

The typical dependent variable in most of the regression models is an energy or emissions indicator such as total or per-capita consumption for a particular fuel or sector. The types of energy sources and energy consumers considered in these studies vary a lot which makes 1:1 comparison difficult. Furthermore, few studies attempt to include embodied energy or consider primary energy consumption, while most take data on final energy consumption of electricity or fuel demand.

Glaeser and Kahn (2010) look at emissions associated with gasoline consumption, public transportation, space heating (fuel oil and natural gas), and electricity usage to determine the carbon dioxide impact of electricity consumption in different major cities.

Sovacool and Brown (2010) take a broader approach by comparing the carbon footprints of 12 metropolitan areas by examining fuel used by vehicles, energy used in buildings and industry, emissions from agriculture, and emissions from waste. Despite data limitations due to inconsistent data sources they draw the conclusion that carbon footprints vary greatly from metropolitan area to metropolitan area. Energy use in buildings is responsible for less than one quarter of emissions in Sao Paulo but above 80 percent in Beijing and Singapore. Transport contributes to only 5 percent of emissions in Beijing but 66 percent in Delhi. In view of the very inhomogeneous results they concluded that different emission sources dominate different cities and metropolitan areas, meaning that
▶ solutions must also differ by location;

- some of the most effective initiatives city planners can undertake to reduce a city's footprint are to encourage compact urban growth through zoning regulations and urban design, sustainable transportation and mass transit, congestion pricing and driving prohibitions, cleaner electricity supply from renewable sources and energy efficiency programmes, and population density through building codes and standards favouring denser dwellings.

Different Independent Variables

What makes studies also difficult to compare and what accounts for the sometimes contradictory findings is the large variety of independent variables employed. Independent variables to be tested or controlled for might include climate, population density, housing characteristics, energy prices, commuting distance, various indicators of sprawl and urban form, and various economic indicators such as GDP, industry mix, or per-capita income.

socio-economic variables

Larivière & Lafrance (1999) develop a statistical regression model that establishes the relationship between the electricity consumption per inhabitant and the socio-economic variables "average inhabitant age", "share of homes heated by electricity", "standardized land wealth per inhabitant", "planning, leisure and culture expenditure per inhabitant" and the variables "annual degree-days below 18°C", "urban density inhabitant per km" for the 45 most populous cities of Quebec. They limit the study to the city's electricity use, owing to the availability and reliability of energy data, and find that high-density cities have a smaller per capita electricity use than low-density cities. Results, however, point out that the impact of increasing population density on electricity-saving is low questioning the fact that urban density is the main factor influencing energy use in cities. Results can be partially explained by the larger number of services in larger cities that offset the energy gain of densely populated areas. Along the same lines, cars are driven longer distances in sparsely populated area, while the per kilometre fuel consumption drops. The authors conclude that factors such as standard of living, value system, city geographic situation, or economic activities are equally important in understanding the energy consumption of a city.

urban forms

Permana et al. (2008) look at different urban forms, defined as "the manifestation of certain physical and spatial growth and development as a result of human activities in an urban area" and compare energy consumption in the context of a developing country, namely Indonesia. They distinguish between:

- planned area with mixed land use;
- unplanned peri-urban area, defined as an unplanned urban expansion into peripheral areas;
- satellite town, defined as an absence of closeness of homes and job places.

Their study is undertaken at the household level, using data on present households' energy consumption acquired through a questionnaire investigating three premises of urban energy use: household, transport, and service/commercial energy consumptions. Additionally, data on energy consumption for household purposes were acquired from their monthly electricity bills and liquefied petroleum gas use and transport energy consumption was calculated from the monthly consumption of gasoline or diesel. They conclude that while results show that energy consumption depends on urban form, the relation between residential energy consumption and increasing level of urbanization of a country is not that clear when comparing, for example, Indonesia and Vietnam or Bangladesh, which have a similar level of urbanization but totally different degree of energy consumption.

Glaeser and Kahn (2010) in their comparison of land use related CO_2 emissions of 48 major metropolitan areas distinguish between central cities and suburbs in order to address the issue of carbon dioxide emissions from driving, public transit, home heating, and household electricity usage associated with new construction. They find that cities generally have significantly lower emissions than suburban areas. Findings indicate that the city-suburb gap can be up to 289.16 dollars for one additional (marginal) household, assuming a social cost figure of 43 dollars per ton of carbon dioxide, and that the gap increases with bigger, richer, and more centralized cities. This relationship can be reversed when, for instance, the city centre consists of older homes which are less energy efficient. Newer homes, however, might be more likely to have air conditioning, which again increases energy demand. Generally, climate plays an important role in energy consumption. For the US emissions were found to be positively associated with average July temperature, negatively associated with average January temperature, and negatively associated with both city population and centralization.

Different System Boundaries

Several studies acknowledge the problem of accounting for emissions not directly consumed and/or produced in the metropolitan area, thus the problem of the hinterland.

types of emissions inventories

Lebel et al. (2007) distinguish between four types of emissions inventories: direct, responsible, deemed, and logistic. Direct emissions are those produced and/or consumed entirely within a metropolitan area. Responsible emissions are those produced within a metropolitan area but consumed elsewhere. Deemed emissions are brought into a metropolitan area but actually emitted outside that metropolitan area. Logistic emissions cover goods and services that are not used in the area but pass through it.

Urban metabolism studies are probably the broadest of approaches, taking into account water, materials, energy, and nutrients/waste flows into and out of an urban region. Kennedy et al. (2007) review studies from eight metropolitan areas to gain insights into the changing metabolism of cities. While urban metabolism studies seem to be more holistic than energy inventories, looking at the "larger picture", there is something to be gained from them. A dimension of material flows that impacts the sustainability of a city is the distance over which materials are transported. As cities grow and transportation infrastructure develops, raw materials seemingly travel increasingly longer distances into cities. This very important aspect is mostly disregarded in energy inventories. Interesting in this context is that in these studies metropolitan regions are often regarded as commutersheds. Furthermore, energy inventories often work with data that do not distinguish between the primary energy consumption and the final energy consumed, which does not account for energy losses in the production of electricity, while urban metabolism studies do.

And a further aspect of the urban energy balance influencing sustainability is the urban heat island. Increases in temperature directly impact summer cooling loads, thus introducing a potentially cyclic effect on energy demand. For U.S. cities with a population greater than 100,000 inhabitants peak electricity loads increase by about 1% for every degree Celsius increase in temperature (Santamouris 2001[13]). This aspect is also hardly ever addressed in energy inventories.

3.3.2.3 Comprehensive Approaches and Relevant Findings

Most of the cited research studies cover one or several aspects of the complex cause and effect relation between land use and energy consumption and only few authors make an attempt to combine all these aspects in an integrative and comprehensive approach.

A very comprehensive and valuable study using a life-cycle approach, hence including grey energy and operating energy, is that of Ott et al. (2008). They assess the primary energy demand of different residential quarters based on 4 case studies in Switzerland, which differ strongly in density and centrality. Included the study were the primary energy consumption of buildings for heating and hot water generation and for electrical appliances and illumination, for supply and disposal infrastructure, such as roads and infrastructure for energy and water services and waste disposal, and for traffic induced by land use, e.g., travel distances, travel frequencies and modal split. Results show that density and type of building construction have a considerable influence on the cumulative primary energy consumption. In particular for traffic the difference between the different settlements is substantial and constitutes a factor of more than 4. The authors also find that the embodied energy in buildings for the construction and demolition phase makes up for only a small fraction of total energy consumed over the lifetime of a building.

Leitner (2009) investigates differences in energy and emission balances between an urban quarter, taking Vienna's 9th district as an example, and Enzersfeld in Lower Austria, as an example of a rural municipality. While the total energy consumption is much higher in the urban setting, breaking the total consumption down to the energy consumption of private households and the number of inhabitants shows that the urban settlement has a much lower consumption (8.90 MWh/cap) as compared to Enzersfeld (13.83 MWh/cap). Main reasons that account for the difference is heating demand which is higher in the rural settlement, most likely due to the larger floor space per resident, and the higher share of energy needed for transportation, probably due to longer travel distances and the predominant use of the private car over public transport. A typical inhabitant of the Vienna district needs on average 1,456 kWh (156 l fuel) per year for travelling by car while a typical inhabitant of Enzersfeld has a more than 3 times higher demand of fuel per year (4,526 kWh, 484 l). Only electricity consumption was slightly higher for the urban settlement.

Also a number of Austrian studies are concerned with modelling the energy demand of a settlement or developing an assessment tool for the evaluation the energy demand of different residential settlements.

[13] Santamouris, M., ed. 2001. Energy and climate in the urban built environment. Athens: James & James as quoted in Kennedy, 2007

The project "*ELAS: Energetische Langzeitanalysen von Siedlungsstrukturen*"[14] chooses a lifecycle approach to analyse housing estates and individual buildings regarding energy consumption, ecological footprint, CO_2 lifecycle emissions and regional economic effects, such as revenues, net value added, jobs created and imports. On the basis of data input from surveys scenarios are defined taking into account the energy needed for construction, renovation, operation, mobility and different lifestyles as well as site-specific parameters. These parameters are incorporated into a model which allows the calculations of the energy consumption of existing and planned settlements over their lifetime. Results of the project will be available as an on-line software tool[15].

Following a similar methodological line, the project "*EFES – Energieeffiziente Entwicklung von Siedlungen*"[16] aims at developing practical management and evaluation tools that provide decision makers with an energy balance for an existing or planned settlement. A set of criteria and predefined standards serve as basis for the assessment of the energy efficiency of a settlement especially regarding building utilisation and mobility behaviour. The project goes one step further and develops also a set of measures including existing, adopted, and new instruments that are applicable to increasing energy efficiency on different level of intervention (spatial planning, traffic management, housing construction subsidies). The selection of tools is based on efficiency and effectiveness criteria that consider least cost as well as social and ecological impacts.

Both these very recent studies are financed by the climate and energy fund and results were not yet available at the time of writing this report.

Another approach is taken by the project "*Energieausweis für Siedlungen*" (Emrich Consulting ZT-GmbH, 2009). Since January 2009 vendors and renters of real estate are obliged to issue an energy performance certificate for the property in question. The assessment focuses on the thermal performance of the building, while other energy-relevant factors, which may completely counteract every energy-efficiency effort taken to improve the performance of the building, are left out of consideration. These are aspects that concern the built environment, such as the building location regarding the distance to work place, schools, shopping facilities, access to public transportation, local climate, and the need for additional infrastructure.

The discrepancy between energy efficiency on the building and on the settlement level was the rationale behind the development of an energy certificate for settlements, which is a planning tool[17] that allows the assessment of the energy efficiency of a settlement along the same efficiency categories used in the certificate for buildings. It is split into the assessment of infrastructure, quality of green space, access to public transportation, local topography and type of building.

14 https://forschung.boku.ac.at/fis/suchen.projekt_uebersicht?sprache_in=de&menue_id_in=300&id_in=7494

15 http://www.elas-calculator.eu/

16 http://www.energieeffizientesiedlung.at/

17 http://www.energieausweis-siedlungen.at

4 Methodology

LAND USE POLICIES and urban development can favour spatial patterns that either contribute to or reduce the demand for energy. General land use related parameters influencing energy consumption are:

- demand for mobility (centralized vs. decentralised approach; mixed land use vs. monofunctional land use)
- demand for heating and cooling (type of housing, building standards)
- urban density (compact cities/settlements vs. low density, discontinuous development)
- supply structures of goods and services (centralized vs. decentralised networks)

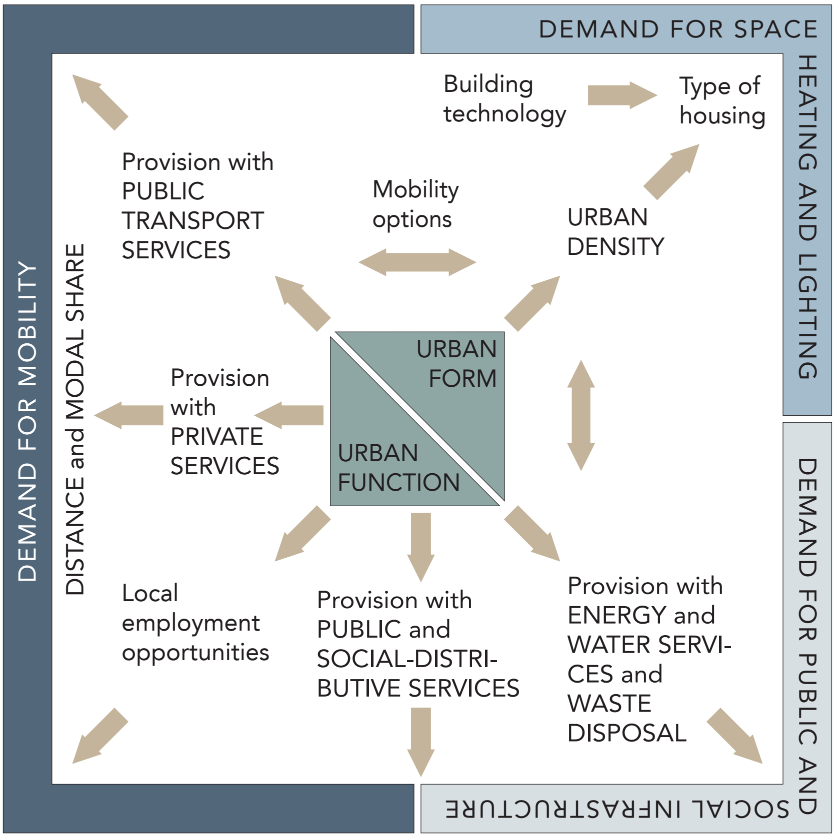

Fig. 3: Schematic diagram on the relationship between urban form and function and patterns of energy demand.

4.1 System Boundaries and Parameters

household primary energy demand

THIS PAPER LOOKS at those aspects of household and municipal energy demand (attributable mainly to households) which are supposed to be influenced by land use and spatial patterns. Industry's and companies' energy demand may also be affected by land use, but as they have very distinct energy consumption patterns they are explicitly excluded from the scope of this study. Furthermore, the study shall explicitly refer to energy demand, as the theoretical energy need under the given assumptions, as opposed to energy consumption, which refers to the actually consumed amount of energy. The strong influence of socio-economic household characteristics speaks against the use of actual energy consumption data. To allow the addition and comparison of different types of energies, final energy demand is converted to primary energy and all values are related to per capita demand.

energy indicator of a settlement

Consequently, the energy indicator of a settlement [kWh/cap/a] shall be defined as the total primary energy demand in kWh per resident for dwelling, infrastructure and transportation. The number of residents includes all residents in a municipality that are listed in the Central Register of Residents. Secondary residence doesn't count as full residence but shall be weighed.

(Urban) spatial patterns can be described from the two viewpoints:

- as pattern of urban function: it describes functional aspects of land use such as the balance of residential, employment, and educational uses as well as distribution, supply, and recreational facilities and their spatial proximity and accessibility.
- as pattern of urban form: it describes morphological aspects of spatial patterns such as monocentric or polycentric structures, compact or dispersed structures, and urban density as the number of residential units or buildings per hectare.

Urban patterns of function and form are thought to influence energy demand on different grounds:

demand for heating and illumination

- by increasing the demand for heating and cooling and illumination

Urban density is mainly a result of the prevailing housing type and floor space per residential unit. Multi-storeyed buildings not only increase urban density, but higher density also directly translates into noticeably less heating energy requirements as compared to single family houses.

Energy demand related to dwelling depends on building-specific parameters such as

- the floor space per resident as the increasing requirements on living space also increase energy demand for heating and illumination;
- the surface to volume ratio as a more compact design avoids heat losses by reducing the heat transmitting building surface;
- the technical energy performance of the building regarding the thermal insulation of walls and roof towards external air, unheated space and the ground, the thermal insulation quality of the windows, the minimization of heat bridges, and the air-tightness of the building according to passive house standards;
- the orientation of the building towards the sun to optimise (passive) solar gains for space heating and to provide a good level of daylighting with additional solar protection devices to reduce cooling demand and to facilitate active (thermal, electrical) use of solar energy.

Energy demand for heating and cooling also depends on external parameters such as

- site specific qualities like local climate and local topography which have an influence on the number of heating days;
- the small-scale settlement structure as an optimised distance between buildings in relation to their height increases solar gains and considerations of urban climate can avoid heat pockets or wind funnelling, but allow the flow of cold air.

demand for public-social and technical infrastructure

- by increasing the demand for public-social and technical infrastructure

Energy demand related to the provision of technical infrastructure and utilities referring to the supply with energy and water services and road infrastructure depends very much on urban density. With decreasing density, street length, sewer length, and water pipe length, etc., per residential unit increase. Providing and maintaining these infrastructures and services is putting a considerable strain on public budget and increases energy demand.

Parameters are
- street length, sewer length and water pipe length, electricity, gas, and district heating (pipe)line length per residential unit.

Energy demand related to the provision of social infrastructure also depends very much on urban density and on the balance between size, number and variety of such services and facilities and the size of the community or neighbourhood. Urban structures may generate traffic or divert motorized traffic from non-motorized traffic, such as walking or biking, and therefore reduce or increase transport energy use per capita. Public-social infrastructure, as understood here, refers to child and elder care including "meals on wheels", home care service, education and health care and waste collection. In the wider sense, it also includes the provision of cultural, sports and other leisure facilities.

Parameters are
- the municipal transport energy use per resident for the provision of public and social services.

demand for mobility

- by increasing the demand for mobility

Energy demand for mobility is strongly related to both urban form and urban function. With increasing urban density and growing population size the provision of attractive urban transportation becomes more viable. Furthermore, mixed land use and the concentration of necessary facilities within short distance allows trip chaining which reduces travel distance and promotes non-motorized mobility such as walking and biking, reducing transportation energy use per capita.
Mixed use is defined as a good balance of
- residential buildings;
- employment opportunities;
- educational institutions (e.g., kindergarten, primary schools, higher education, community colleges);
- facilities and services for basic daily needs (e.g., private services such as groceries, pubs and restaurants, banks, semi-public services such as general practitioners and public services such as community and leisure facilities).

Parameters are
- the travel distance to reach facilities, place of work and educational institution;
- modal share as different transport modes have different fuel consumption per km and capita.

4.2 Indicators to Describe Settlement Types

HIGHER DENSITY and more intense use of land reduces travel distances and implies sharing of infrastructure, energy and water supply, drainage, roads, buildings and public transport, which reduces the energy demand per capita associated with its construction (and possibly maintenance), thus, benefiting from an economy of scale as compared to a more dispersed urban configuration. Furthermore, it allows, for example, the use of combined heat and power and district heating energy provision. Consequently, higher density is mostly associated with lower (or potentially lower) energy consumption.

Nonetheless, authors of studies on the relationship between energy consumption and spatial patterns of urbanization generally acknowledge that the energy consumption attributed to a particular urbanized area can vary widely depending on how "urban areas" are defined and bounded in space (Parshall et al., 2010). Many classification systems of "urban" and "rural" have been proposed and applied. It makes the comparison of results from different studies difficult, which is why some authors made an effort to summarize and classify the variety of approaches.

In an early paper, Alberti (1999) reviews empirical evidence on the relationship between spatial patterns of the urban setting and various dimensions of environmental quality and performance, also focusing, among others, on the relationship between land use and transportation and its energy implications. She criticises that measures of urban form typically employed, such as such as size of built-up area and population density, are usually rather coarse and don't capture characteristics of alternative urban patterns. Therefore, Alberti proposes four structural variables that are relevant at the urban scale and that can be measured:

form, density, grain and connectivity

- Form refers to the degree of centralization/decentralization of the urban structure.
- Density is the ratio between population or jobs and area. However, aggregated density is difficult to disentangle from income.
- Grain indicates the diversity of functional land uses such as residential, commercial, industrial, and institutional. The difficulty is in defining a good measure of land use mix. One possible approach is the use of entropy and dissimilarity indices for measuring land use heterogeneity.
- Connectivity measures the interrelation and mode of circulation of people and goods across the location of fixed activities. While it is an important measure of compactness of urban pattern, no generalizable approach has yet been described for translating transportation infrastructure patterns into a quantitative measure of potential environmental impacts.

A similar classification is suggested by Jabareen (2006) who identifies seven concepts that were repeatedly used to characterize urban form: compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening.

While no consistent terminology to describe urban form exists, a general distinction can be made between indicators that focus on functional aspects of land use and those that focus on morphological aspects of spatial patterns, both having an obvious impact on energy consumption. Consequently, they will be discussed separately and a practical and useful classification scheme suited for the objective of this study will be proposed.

4.2.1 Morphological Parameters

MORPHOLOGICAL PARAMETERS DESCRIBE the physical form and spatial patterns of urbanized areas.

4.2.1.1 Density Parameters

The most common approach in literature is the use of population density as an indicator for classifying into urban, mixed urban, mixed rural, and rural. It seems reasonable to select a density parameter to describe spatial structure as it can be easily determined and the correlation of density with energy consumption has been established in several studies (P. W. G. Newman & J. R. Kenworthy, 1988; Knoflacher, 2006; Hickman & David Banister, 2007). Knoflacher (2006) in his study on the impact of implemented traffic measures on the reduction of energy consumption in urban areas observes that population density per area of built up land showed the clearest correlation of all indicators. Other density parameters commonly used are the number of buildings per hectare or the number of residential units per hectare (Doubek & Zanetti, 1999; Doubek & Hiebl, 2001).

population density

buildings per hectare

residential units per hectare

For the purpose of comparing energy consumption data it is necessary to express consumption as per capita consumption. Therefore, it becomes necessary to not only express density as residential units/ha but to also consider the (average) number of persons per household as this can make a considerably difference[18].

Ott et al. (2008) relate annual primary energy consumption to gross floor area per resident and use the floor-space index (FSI) and the intensity of use per plot to describe urban density. The floor-space index or floor area ratio is the ratio of the total floor space of buildings on a certain location to the size of the land on that location.

floor space index

$$FSI = \frac{A_{floor\ space}}{A_{plot}} \tag{4.1}$$

FSI … floor space index
$A_{floor\ space}$ … gross floor space, or, total area on a certain plot that is covered by all floors of all buildings on the plot
A_{plot} … area of the plot

The total floor space is determined by multiplying the number of storeys with the ground plan of the building. The resulting gross floor space is divided by the total area of the plot to obtain the floor area ratio. The floor-space index is often used in building regulation plans to define the maximum permissible intensity of use related to net building plot and is therefore a measure of urban density.

Another important definitional issue arises from the many possible ways of delineating area. In Austria, population density is often related to the “permanent settlement area”, which describes the area which is suitable for permanent settlement and includes the land use categories “building land” and “agricultural land”.

[18] In 1995 average housing space in Austria ranged between 230 m² and 1.250 m² per residential unit and between 100 m² and 400 m² per inhabitant according to (Doubek & Zanetti, 1999).

Another distinction commonly made is between “gross” building land (*Bruttobauland*) and “net” building land (*Nettobauland*). Gross building land describes the entire area of a building site (the greenfield land) including areas for transportation, public green spaces, and other public facilities, while net building land refers to the entirety of building plots including sealed and non-sealed surfaces, private driveways, parking, etc. Residential density (*Wohnungsdichte*) describes the number of residential units per hectare building land [RU/ha], net residential density, consequently, the number of residential units per net building land.

It is important to bear in mind that it makes a big difference whether the size of the area is determined by considering all “building land” land use category or only the already built up land or whether other land uses, such as traffic areas or other sealed surfaces, are also included. This is shown in Tab. 10. In either case, a strict definition must be introduced and followed consistently throughout the study.

Tab. 10: Comparison of FSI and RU/ha.

Single family detached house	Semi-detached house	Terraced house	Multiple family dwelling (3-4 storeys)	
Maximum obtainable FSI	0.3	0.4	0.7	0.8 – 0.9
Maximum obtainable net residential density (RU/ha)	10 – 20	15 – 27	35 – 52	up to 95

Source: Salzburger Institut für Raumordnung & Wohnen, 2007

Data Sources for Urban Density

Different data sources are available for determining density parameters: population census, building census, residential building statistics on construction activities in the residential building sector, and the Austrian digital cadastral map.

Tab. 11: Data sources for determining urban density.

Data sources:	Data provider	Density parameter	Year
Digitale Katastermappe / Grundstücksdatenbank	Bundesamt für Eich- und Vermessungswesen (BEV)	[buildings/ha built up land]	1995; regular update
Gebäude- und Wohnungszählung	Statistik Austria	[residential units/building]	1991/2001
Wohnbaustatistik	Statistik Austria	[residential units/building]	1998-2003; 2005 - 2009
Siedlungseinheiten	Statistik Austria	settlement units > 500 inhabitants	2010
Population census	Statistik Austria	[inhabitants/ha permanent settlement area]	2001

4.2.1.2 Form Parameters

monocentric or polycentric; compact or dispersed

“Form” refers to the physical layout of a settlement and can be determined by e.g., using cartographic sources. Typical forms are monocentric or polycentric structures, compact or dispersed structures, etc.

An Austrian study that focuses strongly on morphological aspect to describe urban form is Doubek and Hiebl (2001). The focus of their study is on settlements <15,000 inhabitants and they introduce a qualitative distinction based on morphological aspects and assign a quantitative density parameter to it.

- Compact settlements are mainly characterised by higher population density.
- Linear settlements with slightly lower density are settlements that develop along a main road and therefore extend linearly.
- Linear settlements with significantly lower density are settlements that are mainly found in the Alpine regions of Austria, where urban development is typically restricted by the morphology of the valley and therefore has a linear extension.
- Sprawling settlements in peri-urban areas and low-density expansion of urban areas mainly into the surrounding agricultural areas. They show marked population dynamics and low density development at the periphery.
- Larger municipalities with compact centre and low density peripheral areas
- Scattered settlements and traditionally agrarian settlements which are often characterised by a dispersed, polycentric structure.

Data Sources for Urban Form

Urban form has to be determined visually.

Tab. 12: Data sources for determining urban form.

Data sources:	Data provider	Scale	Year
Austrian map (accessible on-line: http://www.austrianmap.at/)	Bundesamt für Eich- und Vermessungswesen (BEV)	1:50,000	regular update in 7 yr intervals
Digital orthophotos (accessible as WMS service and on-line: http://www.geoimage.at/)	Land-,forst- und wasserwirtschaftliches Rechenzentrum GmbH, BEV	Ground resolution 12,5 to 20 cm	2006-2010

4.2.1.3 Mixed Morphological and Functional Parameters

The already cited study of Ott et al. (2008) uses a more complex classification scheme based on a pre-existing typology of Swiss municipalities from 2002. Drawing on a centre-periphery model, it combines functional relations between municipalities as well as demographic (population size, demographic structure, share of single households, density, etc.), socioeconomic, economic (number of jobs in the tertiary sector, number of retail businesses), and aspects of spatial planning (number of leisure and cultural facilities, accessibility, number of passenger cars per inhabitants). The typology comprises 13 types, 7 of which are urban and the remaining 6 types are rural.

4.2.2 Functional Parameters

FUNCTIONAL PARAMETERS are those that describe land use. Mixed land use is considered the most sustainable land use by urban planners as it promotes walking and discourages the use of the car for transportation. It involves a range of complementary land uses that are located together in a balanced mix, including residential, commercial, institutional, recreational development, etc. In reality, however, this desirable mixing of functions is not taking place and rather the opposite tendency can be observed: development takes place mostly at the periphery, where large supermarkets open up on "greenfield sites" and young families settle in newly built detached houses, while the centres slowly empty as groceries shut down and older houses often stay empty over a long period and only the elderly population remains in the village centres.

4.2.2.1 Land Use Mix Parameters

number of jobs per inhabitant

shopping facilities within short reach

As already mentioned, measuring land use mix is rather challenging and not commonly done. The most frequently described parameters in this context are the number of jobs per inhabitants and the number of shopping facilities within short reach. "Reach" is mostly defined as "within a radius" and distances which are covered on food are commonly assumed to be within a threshold of 100 or 500 m (cf. Knoflacher, 2006). Another aspect of land use mix is the availability of leisure facilities in the near vicinity. However, this parameter is somehow problematic as leisure time activities are very heterogeneous and depend very much on personal preferences which may be attributed to age groups, lifestyle groups, etc., rather than to local proximity.

4.2.2.2 Accessibility Parameters

"Accessibility", in essence, describes how well cities and regions are connected within a country's transport network. It plays an important role in regional (economic) development and serves as an indicator for the location advantage of a region or community relative to other regions or communities. Accessibility, in terms of access to main transport networks, is assumed to influence companies' choice of location and might indicate the importance of a municipality as regional or supra-regional centre and is, thus, strongly linked to the centrality concept (cf. 4.2.2.3). Locations with a high accessibility are not necessarily, but very often also the ones with a high degree of centrality.

On a regional scale accessibility describes the interplay of transport systems and land use patterns, while on a local scale accessibility is a characteristic of urban structure. In both cases it measures "the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time (Scheurer & Curtis, 2007)." According to Gaffron (2005) "good accessibility" is understood as "the provision of destinations that are close to origins in space and in time, complemented by the availability of high-quality, environmentally compatible transport links (direct, barrier-free pedestrian and cycle routes and attractive public transport routes)."

The accessibility concept itself is somewhat vague as various definitions and indicators are in use, owing to the fact that different disciplines use the concept for wide-ranging applications (Evangelinos & Ebert, 2011). Numerous accessibility measures have been developed and several classification schemes proposed to structure the large spectrum of methodological approaches (Geurs & Ritsema van Eck, 2001; Schwarze, 2005; Scheurer & Curtis, 2007; Evangelinos & Ebert, 2011). The most important indicators shall be explained in brief:

infrastructure-based accessibility indicators

Infrastructure-based accessibility indicators measure the level of service of infrastructure in an area, either by using the physical distance between infrastructure elements as input or by employing other travel costs or impediments. Travel impediment can be measured as physical (Euclidean) distance, network distance per mode, travel time per mode or by network status (congestion, free-flow, etc.), travel cost per user or for society as a whole, etc.

In order to compare data they must be standardised, meaning that accessibility must be related, for example, to the number of inhabitants in a certain area (e.g., the length of road per inhabitant). These indicators give valuable information on the physical-geographical distance between infrastructure elements but often fail to recognize that destinations of interest may lie far away from that area (Geurs & Ritsema van Eck, 2001). Furthermore, there is no reference to land use patterns or to network constraints, e.g., travel speed or other sources of resistance, nor are behavioural aspects of travel choices taken into account (Scheurer & Curtis, 2007).

activity-based accessibility indicators

Activity-based accessibility indicators, according to Geurs and Ritsema van Eck (2001), measure either distance, contour, potential accessibility, inverse balancing factors, or time-space relation.

Contour measures or cumulative opportunity measures indicate the number of opportunities (e.g., jobs, customers, etc.) reachable within a given travel time or distance by defining catchment areas, also called travel time contours, or isochronic lines. Contours do not differentiate between opportunities inside this area nor distinguish between activities regarding their cost or desirability for users. Similar to them are potential accessibility measures, also called gravity measures. They define catchment areas by measuring travel impediment on a continuous scale and are therefore more accurate representations of travel resistance than contour measures as they weigh opportunities according to their distance, however, at the expense of being less legible (Scheurer & Curtis, 2007).

Inverse balancing factor or competition factor measures incorporate capacity constraints of activities and users into accessibility and consider the presence of competition factors in accessibility. They were developed specifically to introduce competition on the labour market into theoretical accessibility. The measure is rather specific and not often used due to its limited legibility (Scheurer & Curtis, 2007).

Time-space measures focus specifically on the time budgets, or space-time paths, of transport users and measure travel opportunities within pre-defined time constraints. According to Scheuer and Curtis (Scheurer & Curtis, 2007) "the approach is suitable for the evaluation of trip-chaining and of spatial clustering effects of activities."

utility-based accessibility indicators

Utility-based accessibility indicators are founded in economic theory and measure accessibility as the outcome of a set of transport choices made at the individual level. The prime assumption is that individuals always choose the alternative associated with the maximum utility. This approach is relevant for the evaluation of macroeconomic implications of land use and transport infrastructure projects but is otherwise rarely employed (Evangelinos & Ebert, 2011).

In a nutshell, measuring accessibility is a research field in its own right and the purpose of this brief overview of approaches was not to give a full account of all possible measures but to present accessibility as a valuable and well researched indicator to describe spatial structure. Depending on the measure applied, accessibility can serve as both, a morphological and/or functional parameter.

Accessibility Values for Austria

In concrete terms, accessibility parameters seem suited to compare and explain mobility demand of communities, in particular since for Austria detailed accessibility values, based on a 250 m resolution, are available for each municipality[19]. An accessibility model for the whole state territory was first developed and executed in 1997 and then revised in 2005 with the purpose of analysing the quality of supply of the Austrian population with central facilities such as public services and (secondary) schools (Beier et al., 2007). The quality of supply, in other words, the accessibility, was measured in percent of the population able to reach the nearest regional or supra-regional centre within a predefined acceptable period by motorized private and/or public transport.

The approach chosen to determine accessibility, which is a type of contour measure, makes the following assumptions:

In a first step, 269 central places were defined which serve as “nodes” in the model. They correspond to a centrality category of 3 (and higher) and 5 (and higher). Additional central places were introduced representing regionally important school centres as well as some important traffic hubs and central locations in Vienna.

Data on the traffic infrastructure included the categories “highways”, “expressways” as well as “federal, regional and municipal roads” and the “railroad network”. The GIS-based dataset contains road segments divided into vertices and edges with attributes on road category, line length, velocity, capacity, and capacity constraints assigned to them.

The calculations were then based on a 250 m population grid accurately representing the Austrian population based on the 2001 population census. This resulted in 270,000 grid cells for which the fastest connection to the nearest centres was identified by means of a source-destination traffic matrix which contained travel time for each segment in the road network. The travel times for public transport were determined by means of data on stations and time tables. Computing rules assured that only connections within a maximum distance of 1,500 m to the station and a transfer time of maximum 15 minutes were considered. In the following step, access to a regional and supra-regional centre within a defined weighted average travel time of 30’ and 50’ minutes were calculated. The result of the model calculations were accessibility values for each grid cell for the defined 30 and 50 minutes threshold as well as values for each cell regarding the access to a station within a maximum distance of 1,500 m as a measure of the percentage of the population served by public transport.

Results show that access to public transport in Austria is high with 95% of the population having a station located within 1,500 m distance. However, as concerns the connection to a supra-regional centre, only 89% of Austrians can reach such centre within the defined travel time. Furthermore, accessibility conditions differ among regions in Austria;

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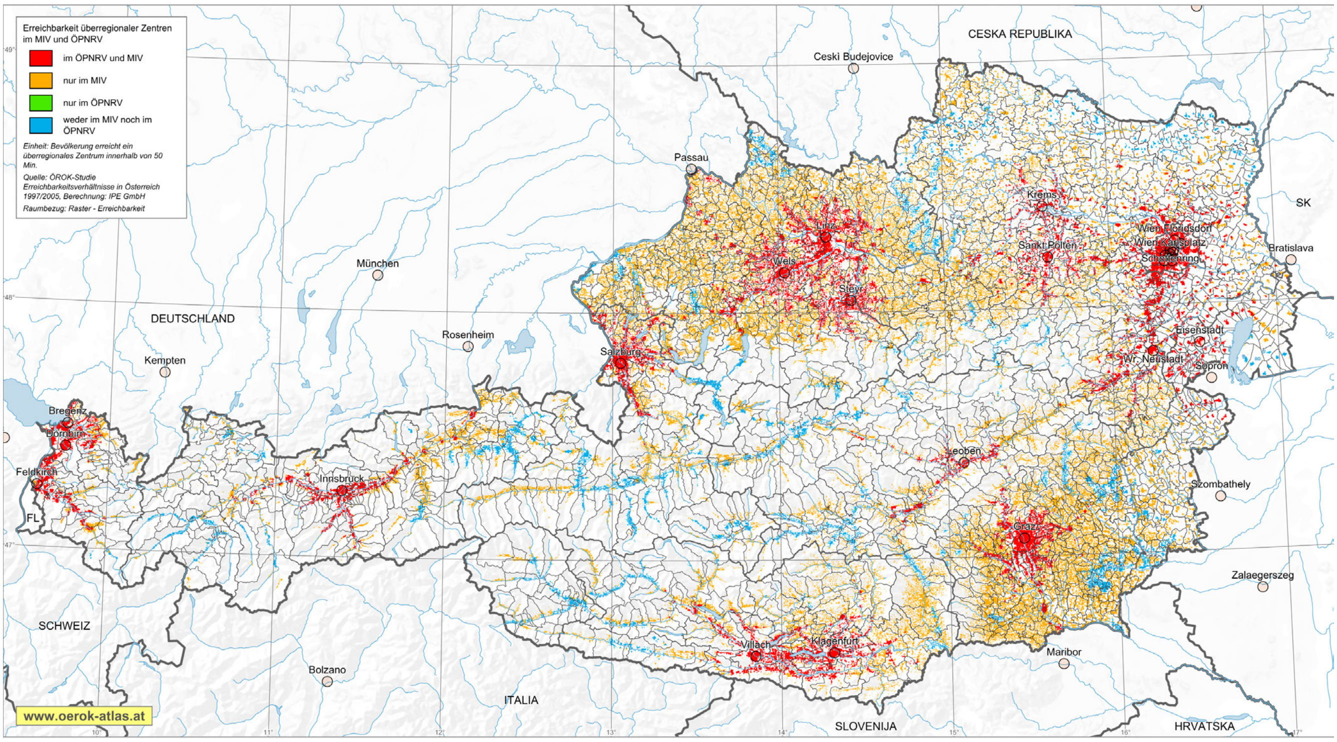
[19] A map representation of data can be accessed on-line: http://www.oerok-atlas.at/index.php

lower values were determined for large and dispersedly populated regions with an unfavourable centre structure, such as Lower Austria, Styria and Upper Austria. Also for the Tyrol, whose population has good access to stations due to the compact settlement structure in the valleys, but at the same time considerably above average travel times to supra-regional centres, a differentiated picture must be drawn.

Fig. 4: Accessibility of supra-regional centres by private and public transport within 50 minutes. (red: private and public transport, orange: only private transport, green: only public transport, blue: not accessible) (Source: http://www.oerok-atlas.at)



4.2.2.3 Centrality Parameters

central place theory

A concept that describes the endowment of a place with tertiary and quaternary services is the "central place theory"[20] which was developed by Walter Christaller, a German geographer, in the 1930s. He explained the size, number and distribution of towns in Southern Germany not from a historical perspective, or as a result of the natural conditions in a particular area, but by looking at a.) the market principle, b.) the principle of the shortest route and c.) the principle of administration.

According to his theory, competition and free prices result in a typical supply structure of goods and services in which consumer goods purchased on a daily basis (e.g., bread) or frequently demanded services (e.g., bank) require a smaller "minimum market" to be profitable while consumer durables (e.g., electronics) or less demanded services (e.g., architect) need a much larger market to bring about the selling of a particular good or service. In return, consumers are also more willing to travel longer distances to acquire a

[20] Christaller, W. (1900) as quoted in (Weichhart, Fassmann & Hesina, 2005).

good which is not an everyday commodity. Thus the more services and goods a place has to offer, the more "central" it becomes, exercising an attraction on an increasingly large number of consumers. It follows that central places are "not products of coincidence but the result of long-term market economic processes" and "have achieved their degree of centrality only partially due to the planning decisions of public authorities (Weichhart, Fassmann & Hesina, 2005)". "By purchasing goods and services, the private households have contributed to the development of a settlement into a central place, and so have the enterprises of the services sector [the tertiary and quaternary sector] through their choice of location."

Basic requirements for the specific rank of a central place in the hierarchy of settlements are therefore access to transportation networks, accessibility, and consumer or user potentials, with the public services sector playing also a pivotal role.

Critique

Being based on a parsimonious and simple model the theory of Christaller appeals due to its clarity, but fails to represent reality with sufficient accuracy. This is mainly because it is based on two erroneous assumptions. First of all, the theory assumes a perfect market and consumers who act as *homines oeconomici* aiming at maximizing utility, an assumption which only partially captures human behaviour and the behaviour of markets. Secondly, the theory overestimates transportation costs and disregards agglomeration advantages. In fact, as people become more mobile, larger distances are more readily accepted and goods and services are often consumed in varying places, a behaviour also termed "polyorientation". Weichhart (1996) found that polyorientation is not the exception but rather the rule. Actual human behaviour strongly diverges from the theoretically predicted and conformity with the theory is overall low.

Furthermore, the central places theory has often been criticised for being a too static concept. In reality, central places are subject to continuous change and their status is not carved in stone. In an empirical study for the *Bundesland* Salzburg, Weichhart (1996) was able to draw some important conclusions regarding the dynamic change of central places. He observed, for a period of 15 years, a general increase in rationalisation and site concentration. In retail, sales floor space has grown and stores agglomerate to so-called retail parks, which is particularly true for certain branches (e.g., grocers, electrical supply stores); but also in public services a tendency to concentrate services and to close subsidiaries (e.g., post offices) and merge administrative districts (e.g., police stations) can be observed. Furthermore, new services emerge while others loose importance or became obsolete. It therefore stands to reason that central places are not invariable and unchanging, but that their status needs to be revised at least every 10 years.

Central Places in Practice

Even though there are legitimate objections to the central places concept as it cannot predict the behaviour of consumers and producers, it is nonetheless a very valuable classification for the functional significance of a municipality and a good indicator for how attractive a place is for non-local residents. There are two good reasons for incorporating the ranking of (central) places in any classification scheme that describes spatial patterns of urbanization in spite of its theoretical weakness: the central place concept has 1.) empirical validity and 2.) practical significance.

Empirical Validity

central places inventory

In a pioneer work Bobek and Fesl (1978) identified central places in Austria and structured them into categories characterised by functions and by a catalogue of 182 central facilities and services. They revised their work in 1980/81 (Fesl & Bobek, 1983), added some new additional central services, and ranked municipalities according to their degree of centrality into:

- principal centre (*Hauptstadt Wien–Stufe 10*);
- regional centres (*Landeshauptstädte –Stufen 9 und 8*);
- secondary centres (*Viertelshauptstädte–Stufe 7*);
- mid-range central places (*Zentrale Orte mittlerer Stufen–Stufen 6-4*);
- low-range central places (*Zentrale Orte der unteren Stufen–Stufen 3, 2 und 1*);
- villages (*unterste bzw. die Dorfstufe–Stufe 0*).

In a first step, 10 degrees of "centrality" were defined based on a prior identification of 182 central services. They were chosen relating to 3 different types of services:
1. private services
2. public services
3. semi-public services (or social services)

private services

public services

Private services (e.g., hairdresser, lawyer, etc.) are characterized by the highest degree of freedom of location and the choice of location is thought to follow the aim of maximising profits. Public services (e.g., district offices, courts, secondary schools, etc.) are provided by the public sector, which decides upon location and the corresponding administrative "district" (e.g. school district, court district, police district, etc.). The decision is based on the principle of providing the population with a spatially inclusive and comprehensive provision of these necessary services. The main difference between private and public services is that public services are not subject to profitability, while private services can only be offered when there is a sufficiently large market for them. This distinction is similar to the distinction between consumer goods and public goods in economics. In the case of private services, it is up to society to "decide" what is a reasonable supply density; for public services the supply density is a political-normative decision.

semi-public or social services

Semi-public or social services have a special status as they are offered by privately run companies that, on the one hand, have a very restricted choice of location, but on the other hand, are only to a limited extent exposed to market forces, thus, have a sort of monopoly. Often these services are social services (e.g., pharmacies, medical doctors that have a contract with an Austrian health insurance, notaries, chimney sweepers) and service providers require a licence in order to be allowed to operate their businesses but, in return, get a territorial exclusivity granted by the public, in most cases, a professional association. Reason for granting local monopolies instead of making these services subject to the free market is the safeguarding of sufficient supply with social services even in more peripheral areas.

producer services

distributive services

Producer services, which are services provided by private suppliers in the area of legal and financial consultancy, marketing and advertising, etc., are destined for the service and producing sector rather than for private households. They were not addressed by the survey of Bobek and Fesl and neither were distributive services, which are rather loosely defined and comprise the trade and transport sector.

Tab. 13: Classification of the tertiary and quaternary sector according to Singlemann and Browning, 1980 (as quoted in Weichhart, Fassmann & Hesina, 2005).

Beneficiary:	Public supplier	Private supplier
household	Semi-public (social) services	Private services
	Distributive services	
household via intermediary	Public services	Producer services

After the indicator services had been empirically determined the ranking of the central places was performed according to their frequency and distribution and on the identification of certain indicator services. All Austrian municipalities were then inventoried regarding their endowment with these central facilities and services and 630 municipalities or places (out of 2,357 municipalities) were identified as central places.

While some subsequent studies for certain *Länder* (e.g., Salzburg, Styria) have been undertaken, the 1981 survey is until now the only comprehensive inventory of Austrian central places. Attempts were made to empirically validate the 1981 ranking by examining the frequency and distribution of several of the original services (e.g., post office, secondary school) and of some newly emerging facilities thought to act as a pull factors (e.g. 'Ikea' store, 'Mediamarkt' store) (Weichhart, Fassmann & Hesina, 2005). Even though some applied research studies modified the 1981 inventory by adding new central places (e.g., secondary school locations, such as in (Beier et al., 2007) it is by and large still in use.

Practical Significance

Beside its use in applied research studies, the central places concept has also practical significance in regional planning. Several *Länder*, as regional planning authorities, have incorporated the central places concept in one way or the other in their legislation. It was either adapted to a model of spatial structuring and used as planning tool aiming to optimise the provision of the population with goods and services or served as a basis for infrastructure planning. In 5 out of 9 *Länder* the term 'central place' is referred to in a binding legal instrument. Carinthia uses it in non-binding documents and others, such as Tyrol, make reference to the concept but use a modified terminology. Only Vienna and Vorarlberg have no indication of central places in their regional planning programmes or laws. Generally, definitions and the use of terms vary, and so does the number of hierarchical levels. Often the central places themselves are inconsistent with the central places identified by Bobek and Fesl.

Although the concept found its way into legislation, it is important to note, as Weichhart et al. (2005) point out, that "even in the public sector, location decisions were only partly made by considering criteria of centrality." Furthermore, those Länder that did adopt the concept often gave too little attention to developing appropriate strategies to implement it and failed to recognize the dynamics of the concept.

Nevertheless, the central places inventory is based on an empirical assessment and considers a large range of services and, thus, reflects the specific hierarchical ranks that places have acquired over time, mostly without planning intervention. It is therefore valid to say that it is a good indicator for the degree of importance of a place as economic and administrative centre and its endowment with job and training opportunities, with educational offerings, with leisure facilities, and other supply facilities. The provision or absence of local facilities and services indicates the necessity to commute, while accessibility points to the distances that need to be travel and the proportion of journeys being travelled by motorised modes.

4.2.3 Proposed Classification Scheme for Settlements

mixed morphological and functional parameter

SETTLEMENTS CAN BE described from the point of view of spatial patterns of urban form and urban function. Since we postulate that land use and urban form related parameters both influence energy demand, a matrix classification for settlements that combines functional aspects of land use and those that focus on morphological aspects of spatial patterns is proposed. The mixed morphological and functional land use parameter draws on the classification of settlements according to 7 structural and density types developed by Doubek and Zanetti (1999) and combines it with the classification of central places developed by Bobek and Fesl (1978), which introduces 6 degrees of centrality.

According to the classification of settlements developed by Doubek and Zanetti (1999) and Doubek and Hiebl (2001), the following definition of urban density will be used in the scope of this paper:

Urban (residential) density is defined as the number of residential units per hectare of net building land according to the cadastral map. Even though the use of residential units instead of residents and of hectares instead of square meter has some disadvantages and flaws it allows the use of an existing classification scheme and facilitates the utilisation of results from the ÖROK studies on technical and social infrastructures. However, it is important to bear in mind that there are considerable differences in density classification of settlements depending on the density definition used. Doubek and Zanetti (1999) find for 12 investigated communities that square meters per residential unit (230 m^2 – 1,250 m^2 per residential unit in 1995) tends to shows more marked differences in density while differences in square metres per resident (100 m^2 - 400 m^2 per resident) are much less pronounced. Differences originate from different age structure and household sizes and the number of vacant apartments also plays a role. Taking the example of Lower Austria, the province is in the mid- or lower range regarding the size of the plot per residential unit, but front-runner in terms of land consumption per capita.

Tab. 14: Proposed matrix for the classification of settlements.

			Functional classes										
			Principal centre	Regional centres		Secondary centres	Mid-range central places			Low-range central places			Villages
	Description	Class	X	IX	VIII	VII	VI	V	IV	III	II	I	0
Morphological settlement classes	urban inner districts	> 60 residential units/ha	x										
	high density settlement	19 – 60 residential units/ha	x	x									
	compact settlement	10 – 19 residential units/ha		x		x		x			x		x
	sprawling settlement in peri-urban area	5 – 9 residential units/ha				x		x			x		x
	low density settlement	5 – 1 residential units/ha									x		x
	scattered settlement with dynamic growth	0,5 – 0,9 residential units/ha											x
	very scattered (traditionally agrarian) settlement	< 0,4 residential units/ha											x

Regarding the classification of central places by Bobek and Fesl (1978), it is recommendable to revise the original ranking based on a number of indicator services and eventually introduce some new central facilities and services. Drawing on the method used by Weichhart, Fassmann and Hesina (2005) this revision can be done by a simple telephone directory search and/or internet inquiry.

4.3 Primary Energy Demand Related to Dwelling

A PLEASANT LIVING environment that provides a place to live, sleep and work and a shelter against environmental influences such as cold and frost, heat and solar radiation, humidity and precipitation, and a protection against wind and noise, etc., is a basic human need. Our modern buildings involve a great deal of (primary) energy consumption related to the conditioning of our buildings in order to create this living environment. Energy demand includes the demand for space heating and cooling, for ventilation, lighting and domestic hot water, all of which we need to maintain the intended ambient room conditions.

In 2009, energy consumption for heating and cooling, including domestic hot water production made up almost 30% of final energy use in Austria (Statistik Austria, 2010b). The considerable saving potential in this realm has to be tapped if we want to achieve the envisioned energy and CO_2 reduction targets. Plenty of incentives have therefore been created to promote thermal rehabilitation, energy efficient technical building systems, and the use of photovoltaic solar panels and solar thermal collectors on rooftops, yet, in practice their energy-saving impact is reduced by the overall increase in living space per person as the average household size has decreased continuously. Beside the tendency for savings to be eaten up through this so-called rebound effect, the effectiveness of measures targeted at improving the energy efficiency of buildings is also slowed down by their failure to show short-term effects. Buildings usually have a lifetime of 60 to 100 years and major renovation works are carried out not more often than every 30 to 40 years. Even heating installations are characterised by longevity and are renewed only after 20 to 25 years on average (Jochum & Pehnt, 2010). This means that possible moments to intervene during the lifecycle of a building, e.g., during the planning phase, the renewal or exchange of the technical building services (heating installations, etc.) or the renovation of a building's insulation, are few. Investment decisions taken have long-lasting consequences on the energy demand of a building and adequate short-term reactions to changes in energy supply or energy costs are hardly possible in existing buildings. Despite the rentability of such measures, annual rates of thermal rehabilitation are low, around 1% in Austria, and inefficient from an economic point of view. This is particularly true for tenement buildings as the costs for improvements in the energy standard of a building have to be borne by the house owner, while the tenant has all the benefit from reduced operating costs. Therefore, the house owner's incentive to invest is low.

However, while thermal insulation can be refurbished and technical building systems can be replaced by newer and more efficient ones, the building design, i.e. the shape and form, the orientation and layout of the façade, etc., are permanent and persistent features of a building that contribute considerably to energy demand.

Two strategies can be addressed that, in combination, are suitable to minimise the energy demand (mainly for heating) of buildings. On the one hand, energy losses can be reduced through compact design as heat is emitted from the building shell and the smaller the surface in relation to the volume, the less heat is emitted. Multi-storeyed buildings require noticeably less heating energy compared to detached single family houses. On the other hand, high insulation standards for walls, roofs, and basements and air tightness combined with a ventilation system that includes efficient air-heat exchangers can curb energy demand. This principle is used in low-energy houses or passive houses, which require no or little external input of energy. Furthermore, possible solar gains can be maximised through a high ratio of windows and glass elements with high-quality glazing on south facades and good daylight supply improves comfort and reduces electricity demand for lighting. Depending on the climate, additional solar protection devices, e.g., shading, reflective roller blinds, reduce demand for cooling. Active solar gains can be achieved by installation of collectors for water heating on roofs, which can turn a building from a zero-energy into an energy-plus house (Gaffron, 2005).

4.3.1 Literature Review

A SUBSTANTIAL BODY of research and literature in the area of energy demand of buildings exists, ranging from the assessment of the thermal quality of individual building elements to the lifecycle assessments of whole buildings and construction types (Schuß, 2004). Since energy certificates became a legal requirement, research in the area of assessment methods for the energy performance of buildings has been promoted and a great deal of literature was added (Pöhn, Pech, Bednar & Streicher, 2007; Pehnt, 2010; Schild & Brück, 2010; Schild & Willems, 2011). However, while the majority of research focuses on the energy demand of individual types of houses few studies look at the level of urban districts. These studies are, however, very valuable because they consider the implications of high density on the demand side of building energy use and on building integrated renewable energy production (such as photo-voltaics) by asking the question when the balance begins to tip in favour of lower densities.

Ratti et al. (2005) explore the effects of urban texture on building energy consumption as highly-obstructed urban areas are deprived of useful daylight and solar gains and necessitate generally higher energy inputs. They analyse the availability of sunlight and daylight on building facades (surface-to-volume ratio and building areas that are within 6 m from a facade), by means of a digital elevation model coupled with a computer model to calculate energy consumption in buildings. For the cities of London, Berlin and Toulouse they find that the variation of energy consumption on urban geometry is relatively small especially, when compared with the impact that can be attributed to the efficiency of building systems or occupant behaviour, but not negligible.

A very useful study is that of Steemers (2003) who breaks urban energy use down to the level of individual buildings (distinguishing between domestic and office buildings) by first looking at urban density in terms of simple parameters such as obstruction angles or plan depth. Then he projects his findings to a 400 m x 400 m part of the city of London, looking at the level of city texture in order to assess energy demand in terms of urban form. For this purpose, the so-called LT energy analysis tool[21], developed by the author, is applied together with computer-based image processing to extract data related to building form for large urban areas. The base-case urban form is then altered by adjusting the building heights. Furthermore, numerous assumptions are made about the detailed characteristics of individual buildings, such as glazing ratio, U-values, building systems, etc. These values had been standardised in a previous study based on a detailed survey of the area and by making informed estimates where necessary. They are, however, project area-specific and therefore not transferable to other study-areas.

benefits from reduced heat losses

The result of the study is the estimation of the order of magnitude of energy implications in relation to urban density for domestic and office buildings in UK's temperate climate. The author finds that "[T]the energy consequences of increasing the average obstruction angles are significant—for example, 10° increase in obstruction results in approximately 10% increase in energy demand." In the specific test area a doubling of density typically increases energy consumption by in the order of 25% for this whole section of the city. This effect can be reduced to 21% by optimising the glazing ratios in response to the level of obstruction. For dwellings in general, the energy implications of compact densification are balanced between the benefits from reduced heat losses and the non-benefits of reduced solar and daylight availability. In particular in office buildings, increased urban density increases energy use because of the reduced availability of daylight in particular. However, this increase is significantly smaller than the energy increase of, e.g., changing from a naturally ventilated office to an air-conditioned office. The overall conclusion is that "[…] other parameters, at the level of individual buildings, [particularly, glazing ratios,] will change the relationship of energy use and urban density."

non-benefits of reduced solar and daylight availability

In either case, this study provides an important insight in the benchmarks at the level of buildings, related to density, that influence energy demand of a city. However, values determined by Steemers for the test area in London would probably have to be adjusted before they can be used for other countries.

lifecycle analysis

Ott et al. (2008) determine the primary energy demand of buildings throughout their lifetime, thus, for the construction, renewal and demolition on the one hand, and energy demand for heating, warm water, electrical appliances, and illumination during the residential use of the building on the other hand, assuming a lifetime of 60 years. They find that primary energy demand of buildings during the use phase is first and foremost dependent on the quality of insulation and, hence, indirectly also on the year of construction. According to their findings, the type of settlement and urban density are secondary, however, their impact is not insignificant. They conclude that compact and dense settlements are therefore crucial prerequisites for achieving a significant reduction in energy demand.

For their assessment, basic information on the level of buildings and settlements, such as dimensions and energy-related characteristics of the buildings, were collected in field surveys and complete with data from the land surveying office wherever possible. Parameters gathered as part of the field survey were:

[21] The tool is not described in any detail in the paper. More information has to be obtained from: N. Baker, K. Steemers, Energy and Environment in Architecture: A Technical Design Guide, E&FN Spon, London, 2000.

On the level of building plot (mostly estimated)

- green spaces (unsealed surfaces)
- sealed surfaces other than the building
- traffic areas
- parking spaces, garage, etc.
- the ground plan of the building

By means of CAD and with the help of cadastral maps the surface areas of the different land uses on the plot were determined in order to establish the intensity of use per plot. Information on the extent of the basement (floor space below ground level) was retrieved from the land surveying office.

On the level of buildings (mostly estimated; some parameters determined by means of photos)

- the number of storeys
- the kind of use(s) and the share of each use
- a basic distinction into single or multi-family home (> 2 residential units)
- technical and structural characteristics (lightweight or massive construction, year of construction or renewal)
- the ratio of windows and other transparent building elements to total building shell

Based on the ground floor of the building and the number of storeys the gross floor area was determined and by dividing it by the total area of the plot, the floor space index was calculated. To exclude energy demand for commercial purposes and small enterprises due to mixed use of a building the floor space for other than residential use was estimated and excluded.

For the assessment of the grey energy embodied in the construction, renewal and demolition the authors used primary energy demand figures per gross floor area and resident [MJ/m^2/resident] (cf. 4.2.1.1) which had been determined in a previous life cycle assessment. These data are based on a simple distinction between single and multi-family home and lightweight and massive construction and are independent from the year of construction.

Tab. 15: Building classification and energy demand figures for construction, renewal, and demolition.

Energy demand for construction, renewal and demolition						
type of use	lightweight construction		massive construction		massive construction + additional basement	
single family home	259 MJ/m$^2_{ERA}$ a	72 kWh/m$^2_{ERA}$ a	243 MJ/m$^2_{ERA}$ a	67.5 kWh/m$^2_{ERA}$ a	246 MJ/m$^2_{ERA}$ a	68 kWh/m$^2_{ERA}$ a
multi-family home	164 MJ/m$^2_{ERA}$ a	46 kWh/m$^2_{ERA}$ a	111 MJ/m$^2_{ERA}$ a	31 kWh/m$^2_{ERA}$ a		
parking	23 MJ/m$^2_{ERA}$ a	6.4 kWh/m$^2_{ERA}$ a				
garage	138 MJ/m$^2_{ERA}$ a	38 kWh/m$^2_{ERA}$ a				

Source: Ott et a., 2008 and own conversion into kWh

Each residential building in the study area was consequently assigned to one of the building classes and to the corresponding consumption figure. Again, buildings that accommodate other than residential uses were only partially considered according to the share of the residential use. Finally, the sum of all energy demand figures was divided by the total gross floor space of the settlement.

As regards the energy demand during the residential use of the building only those types of energy demand were considered which were assumed to be dependent on the settlement structure and on urban density (expressed as floor space per resident). These were heating (and cooling), hot water preparation, illumination, and electrical appliances. Since it was not possible to identify the kind of insulation for each building, average energy demand figures for different construction periods were used. As these parameters are expressed in terms of energy per energy reference area[22] and year, the gross floor area values had to be converted to energy reference areas by multiplication with the factor 0.8.

Tab. 16: Average energy demand figures per energy reference area for heating and domestic hot water for buildings with average insulation. (Ott et al., 2008)

Energy demand of buildings per energy reference area and year		
year of construction	energy demand of building w. average insulation	
before 1976	755 MJ/m^2_{ERA} a	230 kWh/m^2_{ERA} a
1976 – 1980	692 MJ/m^2_{ERA} a	192 kWh/m^2_{ERA} a
1981 – 1985	560 MJ/m^2_{ERA} a	156 kWh/m^2_{ERA} a
1986 – 1990	476 MJ/m^2_{ERA} a	132 kWh/m^2_{ERA} a
since 1990	388 MJ/m^2_{ERA} a	108 kWh/m^2_{ERA} a
Source: Ott et al., 2008 and own conversion into kWh		

The final energy demand for heating and hot water was then determined for each building by multiplying the corresponding construction period-specific energy demand figure with the energy reference area. These energy demand values consumption per m^2 gross floor space make no distinction between single and multi-family homes and are independent of consumer behaviour differences in energy; differences relate only to the quality of the insulation. Ott et al. (2008) argue that energy demand depends, in the first place, on the insulation, while the type of use as single or multi family home was found to be irrelevant. The values obtained where finally converted into primary energy demand figures according to the actual energy mix of each of the 4 case study communities.

Overall, results showed that the primary energy demand for residential use is dominant over the energy demand for construction, renewal and demolition. Nevertheless, the latter plays an important role and must be included if absolute numbers are required. Furthermore, a correlation could be established between density (floor space index) and primary energy demand which decreases with increasing FSI. For primary energy demand during the use phase, no significant correlation with urban density could be established; rather it is the time of construction or renovation of the residential buildings in the settlement which is most relevant. Authors acknowledge that this finding is a result of the type

[22] The energy reference area is the sum of floor areas (including floors above and below ground level) which require heating and cooling. This excludes rooms which are not usually heated, such as washing rooms, boiler rooms, machine rooms, garages, storage rooms etc.

of energy demand figures and density parameter used. The use of the building shell ratio[23], instead of the FSI, would have most likely yielded a different result. An altered picture also emerges when energy consumption is expressed as consumption per resident since the number of m² living space per resident does not necessarily correspond with other measures of urban density.

Primary Energy Demand Related to Household Electricity Consumption

An increasingly important aspect of energy consumption is the growing demand for electricity for illumination and household appliances. Demand for lighting can be linked to the size of living space per resident. However, the final energy use for illumination (2.93%) as compared to heating (28.85%) is rather small, even when corrected for primary energy input (Statistik Austria, 2010b).

socio-economic factors

Floor space per resident may also contribute to electricity consumption, but household electricity consumption is primarily dependent on lifestyle and income.

In a detailed and representative household survey (>1000 households) on the energy consumption of Austrian households, aspects of the individual lifestyle and energy use as well as data on socio-economic and cultural factors were acquired (Bohunovsky, Grünberger, Frühmann & Hinterberger, 2010). Respondents were assigned to 4 types of lifestyle according to cultural, media, music and leisure activity preferences. The defined lifestyles differ in age, in net household income, professional status, and educational level. The result showed that, although energy-relevant behaviour of the different lifestyle types is different, the total energy demand per capita is nearly the same in all four groups. Apparently, households that use energy efficient appliances and live in a building with high energy performance compensate these energy savings by owning more appliances and a larger living space or by showing a more energy-consuming mobility and travel behaviour. On the other hand, households that use heating energy and electricity in an inefficient way are less mobile or use more energy-efficient modes of travelling.

Ott et al. (2008) find that electricity consumption has a high share of total primary energy consumption of households (25-27%) when converted into primary energy, a share which is likely to increase in the future as improvements in insulation will lead to a decrease in demand for heating. Furthermore, they find little differences in energy demand for the different settlement classes. However, no actual consumption data for the settlements were collected, but instead aggregated consumption data for Switzerland were used and allocated to the number of persons and m² per household according to the average floor space per resident in the study areas.

4.3.2 Assessment Methods for Energy Demand Related to Dwelling

IN THE FOLLOWING chapter, assessment methods for the calculation of the energy demand of buildings, including, including the demand for heating energy, energy for the production of domestic hot water and lighting, will be presented.

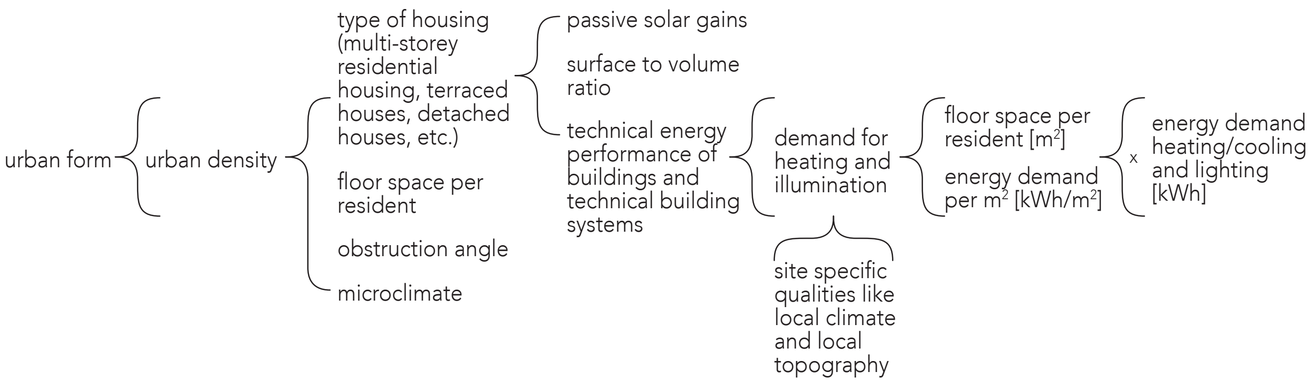
[23] Building shell ratio (*Gebäudehüllziffer*) is a measure for the compactness of a building. It is the ratio of total area of the building shell to total energy reference area. In the present application the building shell ratio represents the average of all buildings in a study area. The roof area was approximated on the basis of the ground plan of the building and an estimated roof inclination of 35°.

4.3.2.1 Demand for Heating, Domestic Hot Water and Illumination

Energy efficiency in buildings is a concept that is used in a wide sense. Contrary to the most common use of the term "energy efficiency", describing the energy conversion efficiency (η) as the ratio between the useful output of a particular energy transforming appliance and input energy, energy efficiency in buildings is more concerned with achieving optimal thermal comfort with a minimized demand of fossil energy (Jochum & Pehnt, 2010). Thermal comfort is usually defined as 20 degrees interior temperature which needs to be constantly maintained during the heating season. Heating demand is strongly connected with site-specific conditions, such as climate, topography and shading cast by neighbouring buildings, vegetation, etc., and building-specific parameters such as the area of the heat transmitting surface, the insulating quality of the opaque and transparent building elements, and the orientation of glazed elements influencing passive solar gains. The type of housing, more specifically, the surface to volume ratio and the floor space per residential unit, has an impact on heating demand per resident and m^2 floor space and links heating demand to urban density. Therefore, multi-storeyed buildings require less heating energy compared to detached single family houses.

Energy required for heating accounts for the largest share of energy demand in buildings. Nevertheless, other energy consuming building services, which can be allocated to floor space, must not be overlooked. These are, on the one hand, technical building services for the generation of space heat and the production of domestic hot water which are subject to conversion and distribution losses. On the other hand, it concerns lighting which is linked to the availability of sunlight but also to the size of living space.

Fig. 5: Factors influencing the household energy demand for heating/cooling and illumination.



4.3.2.2 Building Energy Balance

Numerous approaches to assessing the energy demand of a building have been developed over time. With the implementation of the Directive 2002/91/EU on energy efficiency of buildings and the introduction of mandatory energy performance certificates for existing and newly built buildings these methods have become more advanced and standardized.

While some methods look at the whole lifecycle of a building, thus, at the energy use during construction, renovation, and demolition, the approach foreseen by the EU focuses only on the energy demand during the use of the building and this method has found its way into European and national standards. Generally, energy indicators can be determined on the basis of the calculated energy demand or based on the measured energy consumption. For the latter, actual consumption data (e.g., the heating bills) for at least three consecutive years must be included, taking the mean of all values. While the demand for domestic hot water is largely dependent on personal consumption habits, the demand for space heating is considerably influenced by climate conditions. Therefore, in a first step, data must be corrected for temporary and local variations in climatic conditions. This is necessary to get data which are comparable to corresponding reference data, allowing for the classification of the building into a set of energy performance classes. While in some countries, such as Germany, the calculation of energy demand from measured energy consumption data is admissible, this method is not subject of the Austrian ÖNORM standard ÖNORM B 5055 (Austrian Standards Institute, 2008e). The main disadvantage of the method is the fact that it does not measure the energy demand of the building, but rather the consumption pattern of the residents. While it gives a good indication of the actual energy consumption in a reference period, it generates data which are not standardized and therefore not easily comparable.

In the following sections, departing from the Austrian and European standards the method of calculating the (theoretical) energy demand of a building as opposed to energy consumption will be described, since it warrants the comparability of results. We will adhere to the standards and their nomenclature where applicable, but diverge from them wherever simplifications are possible and sensible.

energy balance

The energy demand of a building can be described as energy balance; as the sum of in and outgoing energy fluxes[24] with the building as the system boundary (Jochum & Pehnt, 2010). The balancing must consider auxiliary, final and primary energy flows. Auxiliary energy is electrical energy used by the technical building systems to support energy transformation to satisfy energy needs, e.g., energy used for pumps and valves (Austrian Standards Institute, 2008d). Final energy is the energy supplied to the end user, thus, the energy demand that the tenant of a building is most interested in as it shows up on his heating bill. And primary energy is the total of energy input required, including grey energy for the extraction, transformation and distribution of the (primary) energy carrier to the end user.

In brief, for the balancing the building is either partitioned into multiple zones or treated as a single zone and the energy balance is split into the energy or heat balance at the building level and at the (technical building) system level. The building energy needs for sensible heating[25] (and sensible cooling) of the building are calculated on the basis of the heat balance of the building zone(s). The resulting energy needs for heating and cooling are then input for the energy balance of the heating and cooling systems and ventilation systems (Austrian Standards Institute, 2008d). If the heat balance is performed over a longer period, e.g., a month, the net amount of heat stored in, or released from the building mass (resulting from dynamic behaviour) becomes negligible.

outgoing fluxes

The outgoing fluxes, also referred to as "losses", comprise the so-called transmission heat losses (Q_T), which result from the escape of warmth from construction elements to

[24] According to the first law of thermodynamics which states that energy cannot be created or destroyed.

[25] Latent heat is not included

outer air, ground or parts of the building not being heated, and ventilation heat losses (Q_V), which describe heat losses via gaps, e.g., at doors, windows, joints or power outlets and building element junctions such as wall-roof junctions and roof-chimney junctions or by natural ventilation. By convention, the transmission and ventilation heat transfer is calculated on the basis of the intended minimum internal temperature, the so-called set-point temperature. Furthermore, there are also system thermal losses of the heating system and installations related to the generation and storage of the heat and its distribution in the building. They are sometimes termed waste heat as they are lost for the user, e.g., the warm flue gas of the boiler which cannot be recovered and leaves the building through the chimney. However, there are technical solutions to recover this heat almost entirely and increase the efficiency of the system.

incoming fluxes

The incoming fluxes that flow into the system include the energy supply in the form of fuels (Q_{fuel}), in other words the "delivered energy […], expressed per energy carrier, supplied to the technical building systems through the system boundary to satisfy the uses taken into account […] (Austrian Standards Institute, 2008d)." It also includes solar heat gains (Q_{solar}) which is "heat provided by solar radiation entering directly or indirectly (after absorption in building elements), into the building through windows, opaque walls and roofs […]" (Austrian Standards Institute, 2008d), as well as heat gains from internal sources ($Q_{internal}$), i.e. metabolic heat that is emitted by humans and animals or heat from electrical appliances inside the building. They are commonly estimated to be around 22 kWh/(m^2_{ERA}·a) (Jochum & Pehnt, 2010). A utilization factor (η) for the internal and solar heat gains takes account of the fact that only part of the internal and solar heat gains is utilized to decrease the energy need for heating, the rest leading to an undesired increase of the internal temperature above the set-point (Austrian Standards Institute, 2008d). According to the Austrian standard ÖNORM B 8110-6 the set-point temperature, in other words, the minimum intended temperature, is assumed to be 20 degrees for the calculation of heating demand and 26 for the calculation of the cooling demand (Austrian Standards Institute, 2011b). In our latitudes, losses are generally higher than the gains, particularly in winter, while in summer, gains might exceed losses which results in a demand for cooling. However, the demand for space cooling is only assessed for non-residential buildings as few residential buildings are equipped with air conditioning.

Beside the demand for heating, other sources of energy demand must be considered in the balance. For one thing, the input energy for the heating of domestic hot water (Q_{HW}) is an important parameter. Required energy depends mainly on personal consumption habits, on the efficiency of the boiler and pumps and also on the quality and insulation of the piping for the distribution of the water within the building. Energy demand for the heating of domestic hot water is usually estimated to be around 12.5 kWh per m^2 energy reference area and year (Jochum & Pehnt, 2010). Heat that is provided without the input of fuel (e.g., thermal solar energy) (Q_r) must be subtracted. Secondly, the energy consumed for cooling of the building ($Q_{cooling}$) must be included, where applicable. Thirdly, the energy needed to cover losses at the level of the technical building systems (Q_t) needs to be taken into account and recovered heat (Q_r) must be subtracted. In a final step, the energy demand for lighting is added to the balance (Q_l).

Finally, all flows are added up to obtain the total energy demand of a building. This sum still refers to final energy without taking into account losses which occur in the process chain from extraction, distribution to transformation. Therefore, each flow must be multiplied with the corresponding primary energy coefficient (f_p) or multiplied with a weighted average of all primary energy coefficients according to the types of fuel used. Consequently, the primary energy demand of a (residential) building Q_P is defined as:

$$Q_P = f_P \cdot Q_{fuel} = f_P \cdot \left(Q_T + Q_V + Q_{HW} - \eta \cdot Q_{solar} - \eta \cdot Q_{internal} + Q_{cooling} + Q_t - Q_r + Q_l \right) \quad (4.2)$$

Q_P … primary energy demand of a building
f_P … (weighted) primary energy coefficient
Q_{fuel} … energy content of the used fuel
Q_T … transmission heat loss
Q_V … ventilation heat loss
Q_{HW} … energy demand for domestic hot water production
η … dimensionless (heat gain) utilization factor [commonly 0.90 – 0.99]
Q_{solar} … solar gains
$Q_{internal}$ … internal gains
$Q_{cooling}$ … demand for cooling
Q_t … thermal losses of the technical building systems relate to the generation, storage, distribution, and emission of heat or hot water
Q_r … recovered energy
Q_l … demand for lightning

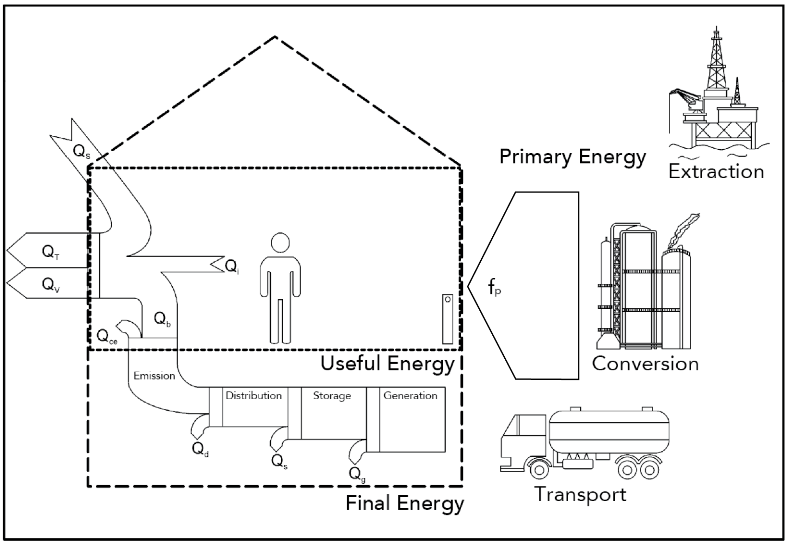


Fig. 6: Primary energy balance of a building. (Schild & Brück, 2010)

4.3.2.3 Energy Demand for Heating

The primary energy demand for space heating Q_H [kWh/a] is a measure for the amount of heat that has to be supplied to the rooms of a building during the heating season in order to maintain a set internal temperature. The energy demand depends on building-specific parameters, such as the building design and building geometry (e.g., compactness, building volume to be heated), technical parameters related to the building (e.g., insulation standards of walls, roof and basement, air tightness, thermal bridges) and to the heating system and installations (e.g., efficiency of the combustion process, system thermal losses).

However, the demand for heating is not only determined by technical parameters on the building-level but also depends on a number of boundary conditions.

local climatic conditions

On the one hand, heating requirements are largely predetermined by local climatic conditions. This does not only concern temperature, but also local exposure to wind, local mist or fog and sun exposure and shading from neighbouring buildings, from vegetation, etc. Moreover, weather conditions can vary a lot from one year to the other, which is why the annual heating demand fluctuates considerably. The variability of the climate makes the introduction of reference weather conditions necessary.

use and intensity of use of the building

On the other hand, the use and the intensity of use of the building play an important role. ÖNORM H 5055 (Austrian Standards Institute, 2008e) generally classifies into residential and non-residential buildings and other (conditioned) buildings. A distinction is made between single family and multi-family residential buildings, offices, education buildings, hospitals (and nursing homes), hotels, restaurants, sports facilities, wholesale and retail services and manufacturing facilities, and indoor swimmingpools. Detailed rules specify the allocation of a building to either one (primary) or multiple uses (Österreichisches Institut für Bautechnik, 2007a). In the case of multiple uses, e.g., retail use on the ground floor, residential use on the upper floor, the energy demand has to be calculated separately for the different building classes. Defining the intensity of use is important since, for example, holiday homes, which are only temporarily inhabited, office buildings, which are unoccupied during the weekend, or hospitals, which require higher room temperatures, have a heating demand that is different from that of a single or multi-family house. To standardize these basic assumptions the Austrian standard ÖNORM B 8110-5 (Austrian Standards Institute, 2011a) defines user profiles for different building categories.

specific heating demand

And finally, the intensity of use also concerns the number of residents per building and building volume to be heated per resident, thus, the heating demand must be expressed as specific heating demand. The energy performance calculation outlined in ÖNORM H 5055 requires the specific heating demand to be expressed as energy per gross floor space since it is targeted at the energy consumption of the building and not at the energy consumption per capita. Sometimes ÖNORM B 8110-6 also refers to the net conditioned floor space, or energy reference area. To convert between conditioned gross floor space and energy reference area the following relation is assumed for residential buildings (Austrian Standards Institute, 2011b):

$$A_{ERA} = A_f \cdot 0.8 \tag{4.3}$$

A_{ERA} … energy reference area [m^2]
A_f … gross (conditioned) floor space [m^2]

The energy demand for space heating is expressed as a long term average over many years in order to be comparable. Boundary conditions for a standardized calculation of heating requirements of a building were defined in ÖNORM B 8110-5 for climate conditions and user profiles.

For the calculation of space heating demand the ÖNORM B 8110-6 standard as well as the EN ISO 13790 standard proceed as follows: first, boundary conditions for climate and the basic use of the building have to be established. In a second step, the building geometry, thus, the ground plan of the building, volume, opaque and transparent surfaces, as well as characteristic parameters of the physical properties of the construction, such as U-values of the different surfaces and the type of heat transfer have to be determined. Then the input parameters for the calculation of Q_h, the losses and gains, are quantified: transmission and ventilation heat losses and internal and solar gains. Finally, the annual energy demand for heating required to maintain the specified set-point temperature in the building is assessed for the local standard climatic condition.

$$Q_h = f_{\mathrm{p}}\left(\left(Q_T + Q_V\right) - \eta \cdot \left(Q_{internal} + Q_{solar}\right)\right) \tag{4.4}$$

Q_h … primary energy demand for space heating [kWh/a]
Q_T … transmission heat loss [kWh/a]
Q_V … ventilation heat loss
η … (heat gain) utilization factor [kWh/a]
$Q_{internal}$ … internal gains [kWh/a]
Q_{solar} … solar gains [kWh/a]

Possible approaches to increasing the energy efficiency of a building are either to minimise transmission and ventilation heat losses or increase solar gains; internal gains play a minor role.

Climate

Located between the Central European continental climate in the East and the Atlantic maritime climate in the North and West, the temperate climate in Austria shows considerable local variations. This is also due to pronounced local topographic variations as a result of its situation in the heart of the Alps. Beside regional climatic influences, local (monthly) average temperatures are primarily determined by altitude.

For a sufficiently accurate description of the local climate the ÖNORM uses a climatographic model developed by the Central Institute for Meteorology and Geodynamics. It divides Austria into 7 climate regions (North, North-influenced by Föhn-wind, West, South-Southwest, Central Alpine, Southern Basins, North-Southeast) according to the mean vertical temperature gradient and defines 3 altitudinal ranges (< 750m, 750 – 1500m, > 1500m). Mean monthly temperature as a function of altitude can be calculated by means of a linear regression model.

mean monthly temperature

$$\theta_e = a + b \cdot \frac{h}{100} \tag{4.5}$$

θ_e … monthly mean temperature [°C]
a, b … regression coefficients
h … altitude, in 100m [m]

The regression coefficients 'a' and 'b' were derived for each month and climate region from climate data for the period 1961 to 1990 and can be found in the standard ÖNORM B 8110-5. Monthly mean temperatures are needed for the calculation of the heating degree days (HDD). HDD are a good indication for the amount of heating that a building needs over a certain period (e.g., a particular month or year) and are, just like mean temperatures, location-specific. For a heating season, the HDD are determined as the sum of all temperature differences between a set indoor temperature of 20°C and the monthly mean outdoor temperature times the number of heating days[26] according to formula 4.6. The HDD are only determined for days with mean temperatures below a certain threshold, in other words for the heating season. In Austria, the heating season is defined as the long-term average number of days with temperatures below the heating threshold temperature of 12°C. Therefore, HDD are given as $HDD_{20/12}$ and have the unit Kelvin·day/year [Kd/a].

heating degree days

$$HDD_{20/12} = \sum_i \left(\theta_{i,h} - \theta_{e,i}\right) \cdot d_i \tag{4.6}$$

$HDD_{20/12}$ … heating degree days [Kd/a]
$\theta_{i,h}$ … set-point temperature for heated space [°C]
$\theta_{e,i}$ … monthly mean temperature [°C]
d_i … number of heating days per month with mean temperature $\theta_{e,i}$ <12 °C [d]

Another meteorological condition defined in ÖNORM B 8110-5 is the average monthly sum of solar irradiance I_S on a horizontal plane. It is determined by means of a second-degree polynomial and can be used for any random oriented or inclined plane by use of transposition coefficients, which can be found in the Annex of the ÖNORM standard. The coefficients a_0, a_1 and a_2 were derived from climate data for the period 1971 to 2000 for each month and climate region and can be looked up in the standard ÖNORM B 8110-5 (Austrian Standards Institute, 2011a). The average monthly sum of solar irradiance is necessary for the calculation of solar heat gains.

solar irradiance

$$I_S = a_2 \cdot \left(\frac{h}{100}\right)^2 + a_1 \cdot \frac{h}{100} + a_0 \tag{4.7}$$

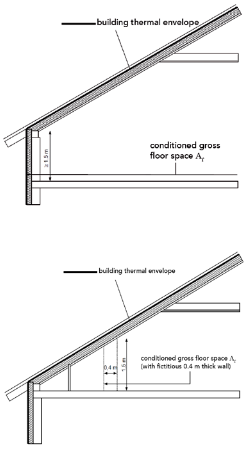
I_S … average monthly sum of solar irradiance [kWh/(m²·M)]
a_0, a_1, a_2 … coefficients
h … altitude, in 100m [m]

Building Geometry

The assessment of the building geometry must be at the beginning of each heating demand calculation. In this first step, the boundary of the building for the calculation is defined. It is preceded by the partitioning of the building into a single zone or multiple zones according to the uses defined in ÖNORM B 8110-5. Other reasons for multi-zone calculation concern different types of construction (lightweight, massive) in one building, varying conditions of use regarding internal gains, different hours in which the space is used, different requirements regarding lightning, etc., and the involvement of different

[26] Long-term average monthly heating days for 170 Austrian municipalities for the period 1971 to 2000 can be found on the website of the Central Institute for Meteorology and Geodynamics. (http://www.zamg.ac.at/fix/klima/oe71-00/klima2000/klimadaten_oesterreich_1971_frame1.htm)

Fig. 7: Rules for determining net and gross floor space of conditioned attics. (Austrian Standards Institute, 2011b)



heating, cooling, hot water, ventilation, and lighting systems. As for the latter, in residential buildings generally a central system that supplies all rooms is assumed and the conditioned space is usually treated as a single zone. Finally, a building also has to be partitioned if the so-called 4-K rule applies. It means that if the set-point room temperatures of two adjacent zones differ by more than 4 Kelvin, they have to be balanced separately.

Basically, ÖNORM B 8110-6 and EN ISO 13790 distinguish between conditioned and unconditioned space or zones of a building, meaning rooms which are heated (or cooled) to maintain a set temperature. The conditioned space can also include rooms which are not equipped with an own radiator, e.g., a staircase or hallway, but which are coupled with conditioned rooms and are supposed to have the same internal temperature. Small spatial variations in temperature within the conditioned space are neglected and the heated space is considered as one zone. Floor area which must be excluded from the conditioned zone are e.g. areas with a temperature difference to conditioned rooms of > 4 K, non-habitable cellars and parts of attic storeys lower than 1.5 m. Detailed rules for determining the size of the conditioned space, which are rather complex, can be found in ÖNORM B 8110-6 and in the OIB-handbook. The EN ISO 13790 standard remains vague on the subject and refers the reader to corresponding national regulations.

conditioned gross floor space

Input parameters that have to be determined according to ÖNORM B 8110-6 are:
The conditioned gross floor space (A_f): It is the total floor space of all conditioned parts of the building. Each storey is thought to have a continuous ceiling, which means that openings in the ceiling for, e.g. staircases or elevator shafts are not subtracted. For a simple rectangular building it is the length x width x number of storeys. In case the attic is also conditioned, the conditioned floor space has to be added to the total gross floor space, following certain conventions. Parts of the floor area with a room height <1.5 m must be subtracted from the net floor space, while 0.4 m are added as "fictitious" wall to obtain the gross floor space (cf. Fig. 6). In case the roof is assembled on a knee wall that is at least 1.5 m high, the floor area of the attic is equal to the floor area of the other storeys.

conditioned gross volume

The conditioned gross volume (V_f): It is the sum of gross volume of all conditioned rooms of the building and is delimited by the outer dimensions of the total space, usually the thermal envelope of the building. The thermal envelope has to be insulated and airtight according to state-of-the-art construction technology of the respective building period. For a simple rectangular building the conditioned gross volume is the length x width x number of storeys x height of each storey. If the attic is part of the living space and therefore part of the conditioned space than its volume has to be determined separately according to the roof geometry. Typically, a distinction is made between flat roof, gabled roof, mansard roof, etc.

The exact determination of areas and volumes of buildings can be found in ÖNORM B 8110-6 and ÖNORM B 1800 (Austrian Standards Institute, 2002).

For some purposes, e.g., the calculation of ventilation heat losses, it is necessary to determine the (net) conditioned air volume, which is defined as the net conditioned floor space x a fixed room height of 2.6 meters.

$$V_V = 0.8 \cdot A_f \cdot 2.6 \qquad (4.8)$$

area of the surface of opaque building elements

The area of the surface of opaque building elements: For each building element the surface area has to be determined according to the basic types of heat transfer. The types of thermal transfer considered are heat transfer between conditioned space and

- external air (e.g., external walls, external ceiling),
- puffer spaces (e.g., unconditioned, closed rooms such as attics, conservatories, glass-roofed atriums or patios, staircases, insulated or non-insulated basements, underground parking, etc.),
- building elements with immediate ground contact (e.g., ground-level floors).

Orientation and inclination of opaque building elements, as measure of the amount of solar radiation energy received on the opaque surface, are not considered. Building elements that have to be measured as part of the building envelope are: the basement ceiling, top ceiling, external wall, roof area, windows, and outer doors. If the attic is conditioned then gable walls and knee walls as part of the façade and the ceiling are added.

area of the surface of transparent building elements

The area of the surface of transparent building elements: This includes glazed envelope elements such as windows or conservatories. The area, orientation, and tilt angle of each transparent element must be identified as they are important input parameters for determining the area of the collecting surface for solar heat gains.

compactness of a building

The compactness of a building is expressed by the characteristic length ℓ_c, as the relation between volume and area of the building envelope according to ÖNORM B 8110-6. However, more commonly used in literature is the reciprocal of the characteristic length, the so-called A/V-ratio. Both parameters give an indication of the form of a building.

$$\ell_c = \frac{V}{A} \qquad (4.9)$$

ℓ_c … characteristic length [m]
V … conditioned gross volume [m^3]
A … surface of the building shell [m^2]

All input parameters ought to be determined with the help of detailed plans of the building. Practice, however, showed that those plans are often not available or don't correspond with the physical reality (Bacher, 2010). In this case, measuring a building's dimensions is a complex task since buildings are seldom simple rectangular blocks. To facilitate the assessment of the building geometry for existing buildings and to make it more cost-efficient, the OIB-handbook (Österreichisches Institut für Bautechnik, 2007a) defines a simplified procedure. In the OIB approach a solid with equal volume and a rectangular, or L, T, U, or O shaped ground plan is inscribed in the building. Deviations from the rectangular shape, such as projections and recesses, (e.g., oriels and recessed loggias) are not considered in a first step. To determine the conditioned gross volume, the ground plan of the building has to be determined (with equal area but with the above mentioned neglect of deviations from a rectangular shape) as well as the number of storeys and the mean net and gross height of the storeys. If the attic is conditioned or partially conditioned it has to be added to the volume. Furthermore, the conditioned floor space and the parts of the building thermal envelope have to be determined. The window area has to be estimated

and assigned to directions.
Finally, the dimensions of projections and recesses (neglecting those <0.5m), which were neglected at first, have to be measured. This includes

- vertical projections and recesses (e.g., staircases),
- horizontal projections and recesses (e.g., oriels and loggias),
- recesses or projections regarding the roof top (e.g., dormers, loggias, roof balconies).

The originally determined areas of the different building elements (opaque and transparent surfaces) are then modified according to the number of projections and recesses by multiplying them with 1.05^n, whereby 'n' stands for the number of vertical and horizontal projections and recesses, for example, 1.05^1 for a staircase, loggia or dower and 1.05^2 for a bay or oriel window, since it projects vertically and horizontally from the façade. The areas of each building element are, thus, increased accordingly, while the gross floor space remains unchanged. The Austrian Institut für Bautechnik[27] provides a calculation sheet which automatically calculates volumes and surfaces if the above mentioned input parameters are known.

The German Institut Wohnen und Umwelt (2005) also developed a simplified method for the assessment of the building envelope by reducing the number of input data based on the statistical evaluation of the data records of more than 4,000 buildings. The research institute[28] has also developed an easy-to-use calculation sheet which requires few input parameters. Based on statistical correlation between floor space and building envelope they developed a simple method for estimating dimensions of building elements of the building envelope (façade, windows, basement ceiling, roof, etc.).

conditioned net floor space

The central variable in this approach is the conditioned net floor space A_{ERA}, also referred to as energy reference area, unlike in the ÖNORM standards which mostly refer to the gross floor space A_f. However, A_{ERA} can be deduced from A_f since the ratio between conditioned net floor space and (conditioned) gross floor space (f_{ERA/A_f}) was found to be nearly constant for buildings without conditioned attic or basement, having a value of 0.75. Only for very large apartment buildings with more than 40 apartments it was found to be lower.

$$A_{ERA} = A_f \cdot 0.75 \tag{4.10}$$

Regarding attics, the average A_{ERA} for attics varies between 50 and 92% of the conditioned net floor space, depending on the geometry of the roof. Therefore a mean value of 0.75 was assumed. As for basements, their conditioned net floor space can take the full range of values from 0 to 100% of that of the full storey.

[27] The calculations sheets can be downloaded from: http://www.oib.or.at/EA-WGe-11-07-2008-V08f%20excel.xls (accessed on 22.09.2011)

[28] The calculation sheets can be downloaded from: http://www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/iwu-kurzverfahren_energieprofil.zip (accessed on 22.09.2011)

Consequently, the conditioned net floor space can be estimated according to the following formula:

$$A_{ERA} = f_{ERA/A_f} \cdot n_{ST} \cdot A_{GP} \tag{4.11}$$

A_{ERA} … conditioned net floor space [m²]
f_{ERA/A_f} … mean ratio A_{ERA} : A_f [0.75]
n_{ST} … number of storeys, whereas
$n_{ST} = n_{BA} + n_{fST} + n_{AT}$
n_{BA} … conditioned floor space basement [0, …, 1]
n_{fST} … number of full storeys [1, 2, 3, …]
n_{AT} … conditioned floor space attic [0, 0.75]
A_{GP} … gross floor space of the ground floor; in other words, the ground plan of the building [m²]

Subsequently, the conditioned floor space is divided by the total number of storeys since the statistical analysis refers to the net floor space per storey.

$$A_{ERA/ST} = \frac{A_{ERA}}{n_{ST}} \tag{4.12}$$

$A_{ERA/ST}$ … net conditioned floor space per storey [m²]

In the steps that follow, dependencies, thus statistical correlations, between $A_{ERA/ST}$ and the different elements of the building envelope were established while controlling for different building types [detached, terraced] and ground plan types [compact, elongated]. By means of linear regression the parameter $\overline{p}$ of the regression line, describing the linear relation between $A_{ERA/ST}$ and the building element, was determined for

- the façade area per storey: a strong correlation of the area of the façade and $A_{ERA/ST}$ with the building type and the ground plan type was found.
- the roof or top ceiling: for buildings with conditioned or partially conditioned attic the correlation is less strong than for buildings with unconditioned attics or flat roofs, yet still remarkably high. For roofs with dowers, the roof area increases by 10 – 30% wherefore a general adjustment factor f_{DOWER} = 1.3 was introduced.
- the basement ceiling or ground floor: the bottommost surface of the building envelope is proportional to $A_{ERA/ST}$ with a proportionality factor of $\frac{1}{f_{ERA/A_f}} = \frac{1}{0.75} = 0.33$.
- the window surface: the relation between window surface, building period and building type was statistically evaluated. Results showed that the correlation with building period and building type is weak, but stronger for the distinction between single family homes ($\overline{p} = 0.20$) and multi-family homes ($\overline{p} = 0.18$).

Results of the statistical analysis were finally validated using the original dataset. The surface areas as originally determined and the results of the estimation of areas by means of the newly developed procedure were compared for the more than 4,000 buildings.

Variance and statistical deviation as well as systematic errors proved low which made further simplifications possible. The resulting parameters allow the calculation of all parts of the building envelope with only few input data necessary:

Tab. 17: Input parameters for the estimation of the dimension of building envelope elements.

Input parameters for the estimation of the dimension of building envelope elements			
variable	*unit*	*description*	*value range*
A_{ERA} or A_f	[m²]	Net or gross (conditioned) floor space; conversion according to formula 4.10	
n_{ST}	[–]	Number of full storeys	
$n_{neighbour}$	[–]	Building type; number of directly adjacent buildings	
		- detached house	$n_{neighbour}$ = 0
		- attached to another building on one side	$n_{neighbour}$ = 1
		- attached to another building on two sides	$n_{neighbour}$ = 2
$T_{ground\ plan}$	[–]	Ground plan type	
		- compact	$T_{ground\ plan}$ = "C"
		- elongated	$T_{ground\ plan}$ = "E"
$f_{BASEMENT}$	[%]	Basement	
		- no basement	$f_{BASEMENT}$ = 0%
		- basement unconditioned	$f_{BASEMENT}$ = 0%
		- basement partially conditioned	$f_{BASEMENT}$ = 50%
		- basement fully conditioned	$f_{BASEMENT}$ = 100%
f_{ATTIC}	[%]	Attic	
		- no attic (flat roof)	f_{ATTIC} = 0%
		- attic unconditioned	f_{ATTIC} = 0%
		- attic partially conditioned	f_{ATTIC} = 50%
		- attic fully conditioned	f_{ATTIC} = 100%
f_{DOWER}	[–]	Correction factor for roofs with dowers and other roof structures	
		- no dower	f_{DOWER} = 1.0
		- dower	f_{DOWER} = 1.3
h_R	[m]	Ceiling height (clear height as the mean value of all full storeys)	

Source: Institut Wohnen und Umwelt, 2005

With these parameters known the missing dimensions of the building envelope can be determined according to the following formulas:

Estimation of the bottommost surface of the building envelope A_{FLOOR}

$$A_{FLOOR} = p_{FLOOR} \cdot A_{ERA/ST} \tag{4.13}$$

Estimation of the topmost surface of the building envelope A_{ROOF} and $A_{TOPMOSTCEILING}$

$$A_{ROOF} = f_{DOWER} \cdot p_{ROOF} \cdot A_{ERA/ST} \tag{4.14}$$

$$A_{TOPCEILING} = p_{TOPCEILING} \cdot A_{ERA/ST} \tag{4.15}$$

Estimation of the window area A_{WINDOW}

$$A_{WINDOW} = p_{WINDOW} \cdot A_{ERA} \tag{4.16}$$

Estimation of the façade area A_{FACADE} per storey

$$A_{FACADE} = \frac{h_R}{2.5m} \cdot \left(p_{FACADE} \cdot A_{ERA/ST} \cdot q_{FACADE} \right) \tag{4.17}$$

Estimation of the conditioned building volume V_V

$$V_V = A_{ERA} \cdot 2.5m \tag{4.18}$$

Tab. 18: Parameters for the estimation of the dimension of building envelope elements.

Parameters for estimating the area of the building envelope							
			flat roof	attic			
				unconditioned	partially conditioned	conditioned	
Topmost surface of the building envelope							
roof area per m² $A_{ERA/ST}$		p_{ATTIC}	1.33	0	0.75	1.5	m²/m²
area of topmost ceiling per m² $A_{ERA/ST}$		$p_{TOPCEILING}$	0	1.33	0.67	0	m²/m²
correction factor dowers	building with dowers	f_{DOWER}	1				
	building w/o dowers	f_{DOWER}	1.3				
Façade							
façade surface area per storey and m² $A_{ERA/ST}$							
ground plan type	compact	p_{FACADE}	0.66				m²/m²
	elongated	p_{FACADE}	0.8				m²/m²
additional area per full storey							
building type	detached	p_{FACADE}	50				m²
	attached to another building on one	p_{FACADE}	30				m²
	on two sides	p_{FACADE}	10				m²
Windows							
window area per m² $A_{ERA/ST}$		$p_{WINDOWS}$	0.2				m²/m²
Bottommost surface of the building envelope							
floor area per m² $A_{ERA/ST}$		p_{FLOOR}	1.33				m²/m²

Source: Institut Wohnen und Umwelt, 2005

Transmission Heat Losses

Once the dimensions of the building envelope are known, the actual input variables for determining the heating demand can be tackled. Most important outgoing flux in a building is the transmission heat loss. The minimization of transmission heat losses can be achieved by

- increasing the compactness of the building volume to be heated, in other words, minimizing the thermal envelope of a building,
- improving the thermal insulation of a building,
- avoiding thermal bridges.

building thermal envelope

The thermal envelope of a building, as the physical separator between the interior and the exterior environment of a building and/or between the conditioned (heated and/or cooled) and unconditioned space of a building is of utmost significance for heat losses related to heat transmission. The thermal envelope, usually sealed towards the outside by means of thermal insulation, is not necessarily identical with the building shell and can deviate considerably from the building geometry. Therefore, for the correct assessment of energy demand for space heating and cooling, the extent of the thermal envelope is the relevant input parameter. According to the standard EN ISO 13790 (Austrian Standards Institute, 2008d) "[t]he boundary of the building for the calculation [is defined by the surface area] […] of all the building elements separating the conditioned space from the external environment (air, ground or water) or from adjacent buildings or unconditioned spaces" and the transmission heat loss must be determined for each single surface individually. The transmission heat loss is consequently defined as

$$\dot{Q}_T = \sum_i^n U_i \cdot A_i \cdot \Delta\theta \qquad (4.19)$$

Q_T … transmission heat losses [W]
U_i … heat transfer coefficient [W/m²·K]
A_i … surface area [m²]
$\Delta\theta$ … temperature difference between the temperatures at both sides of the building element (temperature of the conditioned space minus the temperature of the external environment). The heat transfer to the external environment is negative when the external temperature is higher than the internal temperature. [K]

Q_T describes a heat flux and is defined as the time derivative of the heat transfer per time and unit area. Depending on the method used the calculation of Q_T is performed over different periods of time. The dynamic calculation procedure calculates the heat balance with short time steps, typically one hour, and takes into account the heat stored in and released from the mass of the building. In the (quasi) steady-state method, the calculation step for the heat balance is typically one month or a whole heating season, and the dynamic effects are taken into account by introducing an empirically determined heat gain utilization factor. The international standard ISO 13790 covers both procedures, while the Austrian standard ÖNORM B 8110-6 describes only a quasi steady-state monthly balancing method and a steady seasonal method. The difference between the two lies in the fact that for the monthly method, the heating season and the heating threshold temperature[29] are not pre-defined but result from the balancing (Pöhn, Pech, Bednar & Streicher, 2007). With the last revision of ÖNORM B 8110-6 the monthly method has become the standard procedure.

Formula 4.19 describes the heat flux, however, we are not interested in the heat flux, but in the annual energy demand related to transmission heat loss. For this purpose, every $\Delta\theta$ for days with temperatures below the heating threshold temperature, which in Austria is fixed at 12°C external temperature, has to be determined and added up for the period of the year when the outdoor temperature drops below the critical threshold. The number of days below the heating threshold temperature times the sum of temperature differences are called heating degree days (HDD). The HDD provides a simple metric that can be used, in conjunction with the average U-value for a building, to roughly estimate the amount of energy required to heat the building over a certain period, generally a month or a heating season.

Since heat needs to be provided at the rate at which it is being lost to the environment the total heat loss is the sum of the heat losses per degree of each element of the building's thermal envelope over a whole year. Thus the $HDD_{20/12}$ as expressed in formula 4.6 gives the number of days times the number of degrees below 12°C as a long-term average per year in Kd/a. Since one degree temperature difference in Celsius and Kelvin scale are the same no conversion from Celsius to Kelvin is required.

Therefore, without considering losses due to thermal bridges, the transmission heat loss can be calculated according to:

$$Q_T = \frac{24}{1000} \cdot U_m \cdot A \cdot HDD \tag{4.20}$$

Q_T … thermal heat loss per month [kWh/M] resp. per year [kWh/a]
U_m … average heat transmittance of the building [W/m²K]
A … total area of the thermal envelope of the building [m²]

Q_T is the product of the average heat transfer coefficient of the thermal envelope of the building multiplied by the area of the thermal envelope of the building and the heating degree days. As Q_T has the unit kWh and heating degree days are defined as the number of heating days x degrees, W/K must be converted into kWh per degree per day[30]. ÖNORM B 8110-6 and EN ISO 13790 define Q_T similarly, but use the heat transfer coefficient L_t instead of the heat transmittance U to account for the heat conductivity of a particular building element. L_t is simply the product of the multiplication of the heat transmittance with the area of the thermal envelope and therefore independent of m².

$$Q_T = \sum_i \frac{1}{1000} \cdot L_t \cdot (\theta_i - \theta_e) \cdot t_i \tag{4.21}$$

L_t … heat transfer coefficient of the building [W/K]

[29] The heating threshold temperature (*Heizgrenztemperatur*) defines the outdoor temperature threshold that makes space heating necessary.

[30] This is done by dividing the mathematical expression by 1000 to convert W to kW, and multiplying it by 24 hours in a day to convert from 1 kW to 1 kWh.

θ_i … average internal temperature [°C]
θ_e … average exterior temperature in the respective month [°C]
t_i … number of hours per month according to the user profile defined in ÖNORM B 8110-5 [h/M]

Formula 4.20 shows the linear dependence of Q_T with the area of the surface of the thermal envelope. The larger the surface compared to the conditioned volume, the bigger the heat loss to be expected, a relation which is expressed by the area to volume ration (A/V ratio). A cube has a very low A/V ratio and the more a building's shape deviates from the cube, the larger the A/V ration becomes. A more energy efficient building is thus one that is compact and has an uninterrupted, minimized surface with no or few projections and recesses, while e.g. an elongated building with a jagged surface can be expected to have a comparatively higher heat loss. This means that the shape and form of a building influences its energy performance. However, decisions regarding the architectural design of a building are usually taken on aesthetic grounds rather than for reasons of energy efficiency. Therefore, the more common approach to reducing heat losses is to tackle the second essential parameter, the heat transmittance (Jochum & Pehnt, 2010).

thermal transmittance or U-value

The specific transmission heat loss of construction elements is commonly expressed by the thermal transmittance, also referred to as U-value [W/m²·K]. Thermal transmittance is the rate of transfer of heat through one square metre of a structure divided by the difference in temperature across the structure. It depends on the thermal conductivity of the materials, the material thickness and the near-wall air velocity. The U-value incorporates all three mechanisms of heat transfer, namely the thermal conductance of a structure along with convection and radiation. While conductance is the primary mode of heat transfer impeded by insulation, radiation and convection on the surface of a structure also play an important role. Radiation exchange between the structure and the ambient air takes place right at the interface between the two. The convective heat flux increases with increasing distance from the surface and depends on the near-wall air velocity. Wind increases the convective heat transfer, but convection can also takes place between different layers of insulating material, even tough, in the absence of convection, air and other gases are generally good insulators. In fact, the lowest U-values can be achieved with vacuum insulation.

thermal resistance

The reciprocal value of U, R, is a measure of the thermal resistance of the thermal insulation and is also used to describe a building's insulation effectiveness. Thermal resistance is the temperature difference across a homogenous structure when one unit of heat energy flows through it in one unit of time. The heat flow is initiated by the temperature difference at both sides of the structure. When a structure is made up of layers of different materials, then the thermal resistance of each layer can be summed up. The absolute thermal resistance across the length of the material R_θ [K/W] is defined as

$$R_\theta = \frac{\chi}{\lambda \cdot A} \qquad (4.22)$$

χ … length of the material measured on a path parallel to the heat flow [m]
λ … thermal conductivity of the material [W/K·m]
A … cross sectional area of the material measured perpendicular to the heat flow [m²]

The lower the thermal conductivity, the better is the thermal insulation capacity. The thermal conductivity of a material is defined as the quantity of heat [W] that passes through a cube of that material with the dimensions 1m^3 when the temperature difference of its opposite faces is 1 Kelvin. Standard concrete has a high thermal conductivity of 2 W/K·m, while different insulating materials have a low thermal conductivity of 0.02 to 0.04 W/K·m and even lower for evacuated insulation (Jochum & Pehnt, 2010).

Thermal insulation can, thus, be improved either on the material side, by using insulating material which has optimal insulating properties, meaning low thermal conductivity, or by increasing the thickness of the insulation. However, there are limits to decreasing U by increasing the material thickness. While at first, the U-value rapidly decreases the thicker the material becomes, from a certain point onward the insulation capacity will not improve anymore by growing material thickness. In practice, the thermal envelope consists of several layers of different materials. In this case the U-value is the sum of all individual U-values.

U-values for different construction elements (e.g., windows, concrete) and construction and insulating materials are determined experimentally under laboratory conditions, but can also be measured under real conditions at the building by using heat flux meters. For the calculation of the thermal heat loss of building elements these values can be found in catalogues of accredited testing laboratories that certify building components or must be calculated according to the corresponding standards.

default U-values

For the exact determination of the thermal transmittance detailed information on the type and material selected and the thickness of each layer must be gathered, which might be very cost and labour-intense in the case in existing buildings. Therefore, the Austrian and European standard allows for the use of default values. Default values for buildings built before the 1980s and benchmark values for each *Bundesland* for more recent periods are published in the handbook of the OIB (cf. Tab. 19). Nevertheless, the use of these values poses the problem of comparability since the building period intervals are very different as well as the period covered.

Tab. 19: Default U-values for residential buildings.

U-values for different building elements

building period	building type	basement ceiling	top ceiling	external wall	roof area	windows	outer doors	g-value
before 1900	single family house	1.25	0.75	1.55	1.30	2.50	2.50	0.67
	multi-family house	1.25	0.75	1.55	1.30	2.50	2.50	0.67
since 1900	single family house	1.20	1.20	2.00	0.90	2.50	2.50	0.67
	multi-family house	1.20	1.20	1.50	0.90	2.50	2.50	0.67
since 1945	single family house	1.95	1.35	1.75	1.30	2.50	2.50	0.67
	multi-family house	1.10	1.35	1.30	1.30	2.50	2.50	0.67
since 1960	single family house	1.35	0.55	1.20	0.55	3.00	2.50	0.67
	multi-family house	1.35	0.55	1.20	0.55	3.00	2.50	0.67
Systemized construction (masonry construction or similar)	1.10	1.05	1.15	0.45	2.50	2.50	0.67	
Industrialized (concrete) construction assembled on-site with intermediate insulation	0.85	1.00	0.70	0.45	3.00	2.50	0.67	

Source: Österreichisches Institut für Bautechnik, 2007a

ÖNORM B 8110-6 provides for a simple method for the calculation of the overall heat transfer coefficient L_t [W/K]:

$$L_t = \sum_i f_i \cdot A_i \cdot U_i + L_\psi + L_\chi \tag{4.23}$$

f_i … temperature correction factor for the building element
A_i … surface area of the building element [m²]
U_i … heat transmittance of the building element [W/m²K]
L_ψ … heat transfer coefficient for linear thermal bridge [W/K]
L_χ … heat transfer coefficient for point thermal bridge [W/K]

The temperature correction factor considers the type of heat transfer between the conditioned interior of the building and the ambient air. Heat transfer types are transmission to the external environment, to the ground, through unconditioned spaces or to adjacent buildings. Values for f_i for all building elements are listed in ÖNORM B 8110-6.

thermal bridges

So far, we have not considered thermal bridges. A thermal bridge refers to the part of a structure whose high thermal conductivity lowers the overall thermal insulation of the building, allowing heat to flow through the path of least thermal resistance. They contribute to thermal losses and can make up a substantial part of the overall transmission heat loss. But thermal bridges may also result in structural damages like increased condensation and growth of mould as the surfaces on the interior side of the bridge are usually cooler than the outer surfaces.

Thermal bridges usually occur at building element junctions or where building structure changes material composition. Examples are the junction between external wall and topmost ceiling or bottommost ceiling, window reveals, wall corners, balconies, etc. Thermal bridges give rise to three- or two-dimensional heat flows; however, for most applications a two-dimensional representation of the heat flows generates a sufficiently accurate result. Generally, a distinction is made between geometric, constructional, and material-based thermal bridges[31]. Geometric thermal bridges originate from the building shape. When the outer surface is bigger than the internal surface, e.g., in corners, this leads to a three-dimensional heat flow. Constructional thermal bridges are caused by junctions of different materials with different heat conductivity or a change in the thickness of the fabric. Material-based thermal bridges are caused by inadequate insulation, e.g., of protruding building elements. Typical thermal bridges are balcony slabs, lintels above windows, badly insulated rolling shutter boxes, and concrete or steel parts linking inside and outside temperatures.

Another distinction is between a linear thermal bridge, which is a thermal bridge with a uniform cross-section, and a point thermal bridge, which is one that can be represented by a point thermal transmittance.

ÖNORM B 8110-6 proposes different methods for the calculation of heat loss related to thermal bridges: the exact calculation according to ÖNORM EN ISO 10211 (Austrian Standards Institute, 2008a), a simplified method according to ÖNORM EN ISO 14683

[31] Information taken from http://www.ecobine.de/indexc.php?SESSID=&id=2.2.6.2&kurs=9&l=en [Accessed on 10/4/2011]

(Austrian Standards Institute, 2008b) which provides default values for ψ and allows the reduction of the number of thermal bridges considered in the calculation. According to formula 4.24 the heat transfer coefficient for linear and point thermal bridges L_ψ, L_χ [W/K] is calculated as follows:

$$L_\psi + L_\chi = 0,2 \cdot (0,75 - \frac{\sum_i f_i \cdot A_i \cdot U_i}{\sum_i A_i}) \cdot \sum_i f_i \cdot A_i \cdot U_i \geq 0.1 \cdot \sum_i f_i \cdot A_i \cdot U_i \tag{4.24}$$

f_i … temperature correction factor for the building element
A_i … surface area of the building element [m²]
U_i … heat transmittance of the building element [W/m²K]

If the equation is true than the heat transfer coefficient for linear and point thermal bridges is equal to the left hand side of the equation; otherwise it is equal to the right hand side of the equation.
The OIB provides a calculation sheet for the standard method and for the simple method which facilitates the calculation of the overall transmission heat loss.

The German Institut Wohnen und Umwelt (2005) has also developed a simple method for calculating the heating energy demand based on default values for heat transmittance. The required input parameters are reduced to a minimum and generally don't require an inspection of the building. Based on the assumption that each building period has a typical prevailing insulating system, typical values for the particular systems were researched. The default U-values require only a differentiation between construction type and building period. Regarding construction type, the distinction is made between massive construction and light or wooden construction which generally has a lower U-value. As for the building period, the heat transmittance value of opaque building elements can deviate considerably from the original U-value after an existing building was thermally renovated.

additional insulation

The effect of additional insulation, which depends very much on the thickness of the insulating material, on the U-value is determined as follows:

$$U_I = \frac{1}{\frac{1}{U_0} + \frac{d_I}{0.04\, W/mK}} \tag{4.25}$$

U_I … default U-value for the building element after thermal renovation [W/m²K]
U_0 … default U-value for the building element before thermal renovation [W/m²K]
d_I … thickness of the insulating layer [m]

Concerning windows, a distinction is made between the following categories: wooden windows with single and double glazing and insulating glass with plastic, aluminium, or steel frame. Finding out whether the glazing is made of insulating glass would require an on-site inspection. To avoid this step, the authors made use of the fact that since the introduction of the thermal insulation regulation in Germany in 1995 the use of insulating

glass has increased sharply. Therefore, the date of the installation of the window can be used as a proxy. Typical g-values were also assigned to each class as they are decisive for the determination of solar gains.
The following input parameters need to be known:

Tab. 20: Input parameters for the estimation of heating energy demand.

Input parameters for the estimation of the heating energy demand			
variable	unit	description	value range
CT	[–]	construction type (separately for A_{ROOF}, $A_{TOPMOST\ CEILING}$, A_{FACADE}, A_{FLOOR})	
		- massive construction	CT = "M"
		- light construction (wooden construction)	CT = "W"
$A_{THERMAL\ RENOVATION}$	[%]	thermal renovation of an opaque building element	
		- area in percent of total area of building element	$A_{THERMAL\ RENOVATION}$ = 1-100%
I	[cm]	thickness of additional insulation (separately for A_{ROOF}, $A_{TOPMOST\ CEILING}$, A_{FACADE}, A_{FLOOR})	
		- insulation thickness in cm	$I \in \mathbb{N}$
$BP_{building}$	[–]	building period	
		-1918; 1919-1948; 1949-1957; 1958-1968; 1969-1978; 1979-1983; 1984-1994; since 1995	$BP_{building}$ = 1-8
BP_{window}	[a]	approximate date of installation of windows	
		- year	$BP_{window} \in \mathbb{N}$
W	[–]	type of windows	
		- wooden windows with single glazing	W = 1
		- wooden windows with double glazing	W = 2
		- insulating glass with plastic frame	W = 3
		- insulating glass with aluminium or steel frame	W = 4

Source: Institut Wohnen und Umwelt, 2005

The authors provide an unprotected Excel-calculation sheet which can be modified to adjust for the Austrian conditions (e.g., climate, etc.).

			Building periods*							
			until1918	1919 to 1948	1949 to 1957	1958 to 1968	1969 to 1978	1979 to 1983	1984 to 1994	since 1995
			Default values for heat transmittance [W/m²K]							
Roof	massive construction (in particular flat roofs)		2.1	2.1	2.1	2.1	0.6	0.5	0.4	0.3
	wooden construction (in particular pitched roofs)		2.6	1.4	1.4	1.4	0.8	0.5	0.4	0.3
Topmost ceiling	massive ceiling		2.1	2.1	2.1	2.1	0.6	0.5	0.4	0.3
	ceiling with wooden beams		1.0	0.8	0.8	0.8	0.6	0.4	0.3	0.3
External walls	massive construction (masonry, construction, ...)		1.7	1.7	1.4	1.4	1.0	0.8	0.6	0.5
	wooden construction (half-timbered house, wooden prefabricated house, ...)		2.0	2.0	1.4	1.4	0.6	0.5	0.4	0.4
Building elements with transmission to the ground or basement	massive building elements		1.2	1.2	1.5	1.0	1.0	0.8	0.6	0.6
	ceiling with wooden beams		1.0	0.8	0.8	0.8	0.6	0.6	0.4	0.4
Windows	wooden windows, single glazing	g^ = 0,87	5.0	5.0	5.0	5.0	5.0	–	–	–
	wooden windows, double glazing**	g^ = 0,75***	2.7	2.7	2.7	2.7	2.7	2.7	2.7	1.6
	plastic windows, insulating glazing	g^ = 0,75***	–	–	–	3.0	3.0	3.0	3.0	1.9
	aluminium or steel windows, insulating glazing	g^ = 0,75***	–	–	4.3	4.3	4.3	4.3	3.2	1.9

**) building period (year of construction of the building (or a building element in the case of newly installed elements, esp. windows)*
***) insulating glazing, box-type windows or double-hung sash window*
****) as of building period 1995: g^ = 0,6*

		until1918	1919 to 1948	1949 to 1957	1958 to 1968	1969 to 1978	1979 to 1983	1984 to 1994	since 1995
Windows g-values	wooden windows, single glazing	0.87	0.87	0.87	0.87	0.87	–	–	–
	wooden windows, double glazing**	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.60
	plastic windows, insulating glazing	–	–	–	0.75	0.75	0.75	0.75	0.60
	aluminium or steel windows, insulating glazing	–	–	0.75	0.75	0.75	0.75	0.75	0.60

Source: Institut Wohnen und Umwelt, 2005

Tab. 21: Default U-values and g-values. (Institut Wohnen und Umwelt, 2005)

Ventilation Heat Losses

Ventilation heat loss, beside the heat loss due to heat transmission, constitutes the second most important heat loss in the energy balance of a building. Losses result from the exchange of warm air with colder fresh air from the outside. The ventilation of a building ventilation losses

is necessary not only to provide fresh air and get rid of CO_2 and bad odours, but also to control humidity and prevent mould. The heat transfer due to ventilation [kWh/a] is defined as follows:

$$\dot{Q}_V = \sum_i \frac{1}{1000} \cdot L_V \cdot (\theta_i - \theta_e) \cdot t_i \qquad (4.26)$$

L_V … heat transfer coefficient by ventilation of the building [W/K]
θ_i … average internal temperature, or set-point temperature [°C]
θ_e … average exterior temperature in the respective month [°C]
t_i … number of hours per month according to the user profile defined in ÖNORM B 8110-5 [h/M]

ventilation heat transfer coefficient

The heat transfer coefficient by ventilation is calculated according to the following formula:

$$L_V = c_{p,L} \cdot \rho_L \cdot v_V \qquad (4.27)$$

L_V … heat transfer coefficient ventilation [W/K]
$c_{p,L}$ … heat capacity of air per volume [1.006 kJ/kgK]
ρ_L … density of air [12 kg/m³]
v_V … air flow volume [m³/h]

air flow volume

The multiplication of the density of air with the heat capacity of air gives 0.34 Wh/m³K. The air flow volume is defined as

$$v_V = n_L \cdot V_V \qquad (4.28)$$

n_L … air exchange rate according to ÖNORM B 8110-5 [0.4 h^{-1}]
V_V … conditioned air volume (cf. formula 4.8)

Since air exchange depends largely on user behaviour and on the air tightness of the building, ÖNORM B 8110-5 defines a standardised air exchange rate. It describes how often the air volume of a room is exchanged during one hour and is assumed to be 0.4 per hour for residential buildings. Generally, intentional ventilation can be achieved by simply opening the windows, also referred to as natural ventilation, or controlled by means of a mechanical ventilation system. A ventilation system can be equipped with a heat recovery system, which considerably improves its energy efficiency. Such technology is used, for example, in passive houses. Most residential buildings, however, are not equipped with a mechanical ventilation system but ventilate naturally. In this case, the heat transfer due to ventilation depends only on the local climate conditions.

Solar Heat Gains

So far we were focusing on outgoing fluxes in the energy balance; however, there are also positive fluxes. Therefore, a second possible approach to improving the energy efficiency of a building, besides decreasing losses, is to increase heat gains.

Transparent surfaces can trap radiation as short-wave solar radiation can easily penetrate through glass, while long-wave heat radiation is retained. This heat input is also called solar gains, or passive solar gains as opposed to solar radiation that is actively collected by photovoltaic cells of a photovoltaic system. Solar gains reduce the heating demand during the heating season but are not always welcome and may be compensated by the need for a cooling system in summer. However, according to ÖNORM B 8110-6 cooling demand is not considered for residential buildings as the number of residential buildings with air conditioning is rather small. The degree of utilization of the heat gained, thus the actual reduction of heating demand, is described by the correction factor.
Solar gains depend on

- the intensity of solar radiation in a particular location,
- the orientation of the collecting areas, mainly the glazing,
- the size of the collecting areas,
- the solar transmittance and absorption and thermal heat transfer characteristics of the collecting areas and
- the permanent and moveable shading.

The actually exploitable solar radiation depends very much on the orientation of the building, in particular, on the orientation of the windows. The permanent or temporary shading, either cast by the building itself or by neighbouring buildings or vegetation, also plays an important role. Furthermore, the solar transmittance or permeability of the transparent surfaces needs to be considered. This is expressed by the g-value, a coefficient which describes the fraction of incident solar radiation that actually gets through a window as heat gain and is expressed in %.

g-value windows

$$g = \frac{transmitted\ radiation}{incident\ radiation} \tag{4.29}$$

The g-value is composed of the direct transmission of energy and the secondary dispensation of heat of the glazed surface toward the interior, which occurs on the basis of absorbed solar rays. Typical g-values range between 0.3 for solar protection glazing and 0.85 for single glazing without a solar protection film (Jochum & Pehnt, 2010).

solar gains

Solar gains in kWh/a can be calculated according to the following formula:

$$\dot{Q}_S = \sum_i \left(\sum_j \left(I_{S,j} \cdot \sum_k A_{trans,h,k,j} \right) \right) \tag{4.30}$$

$I_{S,j}$ … solar irradiance; the mean energy of the solar irradiation over a month per m² collecting area 'k' with a given orientation and tilt angle 'j' [kWh/(m²·M)]
$A_{trans,h,k,j}$ … solar effective collecting area of the transparent surface 'k' with a given orientation and tilt angle 'j' [m²]

solar effective collecting area

The solar effective collecting area of glazed envelope elements (e.g., windows) is given by equation 4.31.

$$A_{trans,h} = A_{glazing} \cdot F_S \cdot g_{glazing} \tag{4.31}$$

$A_{glazing}$ ... overall projected area of the glazed element (e.g., window area) [m^2]
F_S ... shading reduction factor for the solar effective collecting area [0-1]
$g_{glazing}$ ... solar effective g-value of the glazing [0-1]

overall area of glazed elements

The overall projected area of the glazed element is defined as

$$A_{glazing} = A_{window} \cdot f_w \quad (4.32)$$

A_{window} ... window area (*Architekturlichte*) [m^2]
f_w ... frame area fraction; default value for the ratio of the projected frame area to the overall projected area of the glazed element. [0.7]

The shading reduction factor F_S is a value between 0 and 1 that expresses the reduction of incoming solar irradiation on a given surface as a result of permanent shading caused by neighbouring buildings, topography and vegetation, or shading that is cast by the building itself. The factors for all three components can be looked up in tables according to inclination, horizontal angle and orientation of the shade in ÖNORM B 8110-6. For the simplified method it is permitted to use the default values F_S =0.85 for single family and terraced houses and F_S =0.75 for all other buildings.

solar effective g-value

The solar effective g-value of the glazing is defined as

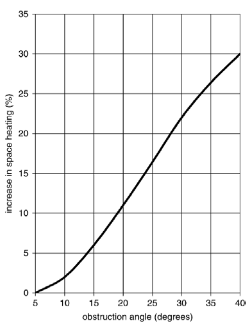
$$g_W = 0.9 \cdot 0.98 \cdot g \quad (4.33)$$

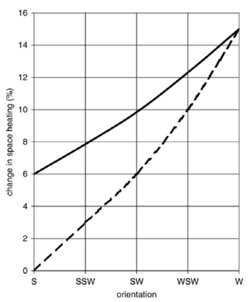
g ... solar transmittance of the glazing for perpendicular radiation and clear glass. To correct for non-perpendicular radiation [0.9] and dirt on the glass [0.98] a correction factor is introduced. Default g-values for different types of glass can be looked up in ÖNORM B 8110-6.

Solar heat gains also concern opaque building elements, but as they constitute only a small portion of the total solar heat gains and are partially compensated by radiation losses from the building to the ambient air, they are not usually considered.

A drawback of the simplified methodology proposed by ÖNORM B 8110-6 is the fact that the implications of urban densities on solar gains are not sufficiently taken into account in this approach. Highly-obstructed urban areas are deprived of useful daylight and solar gains which increases the energy demand for heating and illumination. Generalizable findings from literature, such as the (near linear) relation between the effect of obstruction and orientation of the building on space heating and the relation between building form and heat loss determined by Martin (1972) and Steemers (2003) are a viable alternative to the actual calculation of shading for each individual building.

Fig. 8: The effect of obstruction and orientation on space heating demand. (Martin, 1972)





Internal Heat Gains

Internal heat gains is heat emitted by humans (and animals) or electrical appliances. According to EN ISO 13790 "[i]nternal heat gains [...] consist of any heat generated in the conditioned space by internal sources other than the energy intentionally utilized for

space heating, space cooling or hot water preparation" and include
- metabolic heat from occupants and dissipated heat from appliances,
- heat dissipated from lighting devices,
- heat dissipated from, or absorbed by, hot and mains water and sewage system,
- heat dissipated from, or absorbed by, heating, cooling and ventilation systems,
- heat from or to processes and goods.

There are methods for the calculation of internal heat gains of the various sources, either by looking at the consumption of electrical power or by considering the average power output of lightning and electrical appliances and the metabolic heat emitted by humans. However, given the small contribution of internal gains to total heat gains in residential buildings, the use of a standard value is justified. ÖNORM B 8110-5 provides a default value of $q_{i,h,n}$ = 3.75 W/m² per day for residential buildings during the heating season. The German Energiesparverordnung estimates Q_i to be 22 kWh/m²$_{ERA}$/a for living space (Jochum & Pehnt, 2010). Internal gains [kWh/a] are thus defined as

internal heat gains

$$\dot{Q}_i = \sum_i \frac{1}{1000} \cdot q_{i,h,n} \cdot A_f \cdot 0.8 \cdot t_i \tag{4.34}$$

$q_{i,h,n}$ … heat flow rate from internal heat sources per m² defined in ÖNORM B 8110-5 [3.75 W/m²]
A_f … gross conditioned floor space [m²]; the factor 0.8 converts the gross conditioned floor space into the net conditioned floor space A_{ERA}
t_i … hours per month according to the user profile in ÖNORM B 8110-5 [h/M]

4.3.2.4 Energy Demand for Technical Building Systems

The provisions of buildings with space heat, hot water, fresh air, space cooling, air humidification and dehumidification, and lighting is subsumed under the term "technical building systems". The energy demand for technical building systems according to the methodology defined in the ÖNORM standards is subdivided into energy demand for the (central) heating system and domestic hot (drinking) water system (ÖNORM H 5056), the ventilation system (ÖNORM H 5057), the air conditioning system (ÖNORM H 5058) and illumination (ÖNORM H 5059). However, for the assessment of the energy use in residential buildings only the calculation of system energy requirements and system efficiencies of space heating systems and domestic hot water systems is required.
Generally, the energy analysis and assessment of energy demand for the provision of technical building systems is split into 4 process steps (Koenigsdorff, Becker, Floß & Haibel, 2010):
1. generation
2. storage
3. distribution in the building
4. delivery to the end user (emission)

The calculation method for determining system thermal losses is based on the separate analysis of the subsystems "emission", "distribution", "storage" and "generation", thus, structured according to the components of the heating system. The calculation direction is from the energy needs to the source, e.g., from the building energy need to the primary energy.

The basic input variable in the calculation of energy use is the demand for thermal energy to maintain a set indoor temperature and to heat a fixed amount of hot water to a set water temperature. The actual indoor temperature, however, changes almost constantly, while the heating and hot water system cannot provide the demanded quantities just in time. Reasons are the thermal inertia of the air and the imperfect measuring and control accuracy of the thermostatic valve. Therefore, the system has to provide more heat than physically necessary to maintain the set point temperature (Koenigsdorff, Becker, Floß & Haibel, 2010).

Thus part of the energy demand can be ascribed to operating conditions, such as the heat demand, the chosen water temperatures, or the generator room temperatures. Additionally, losses occur in each of the four steps in the process from production to delivery which are due to system energy performance and are expressed as efficiencies. The resulting additional demand exceeds the actual demand for space heating and domestic hot water heating determined previously.

efficiency of a technical building system

Another aspect must be considered: losses that occur within the thermal envelope of the building can be partially recovered. The calculation of the recoverable proportion is expressed as efficiency, as the ratio between input and output (Austrian Standards Institute, 2007a). The efficiency η of a subsystem i is defined as:

$$\eta_i = \frac{Q_{i,out} + f_j \cdot E_{el,i,out}}{f_y \cdot Q_{i,in} + f_z \cdot W_{i,aux}} \tag{4.35}$$

$Q_{i,out}$ … heat output of subsystem i
$f_{j,z,y}$ … primary energy coefficient, energy conversion factor of energy requirements to primary energy
$E_{el,i,out}$ … electricity output of subsystem i
$Q_{i,in}$ … heat input of subsystem i
$W_{i,aux}$ … auxiliary energy of subsystem i

expenditure factor

Another way of expressing the energy performance of a system or sub-system is the expenditure factor, e, as the reciprocal value of the efficiency.
For each subsystem, the system thermal loss, Q_{H}, is calculated and added to the system heat output in order to determine the required heat input. Where applicable, the auxiliary heat W_H used by the heating system is calculated separately and added to the energy losses of the sub-system. Auxiliary energy is "electrical energy used by technical building systems for heating, cooling, ventilation and/or domestic hot water to support energy transformation to satisfy energy needs (Austrian Standards Institute, 2007a)."
To determine the total energy demand, the system thermal losses, the recoverable system thermal losses, and the auxiliary energy of the sub-systems of all relevant subsystems of the heating system are summed up.

Generally, ÖNORM EN 15316 provides for different calculation methods according to the level of accuracy required (Austrian Standards Institute, 2007a). The most accurate values for losses or efficiencies are achieved with dynamic simulations that take into account the time history of variable values, e.g., external temperatures, distribution water temperature, generator load. A somewhat less accurate is the calculation of losses, auxiliary energy, or efficiencies for each subsystem on the basis of dimensions of the system, duties, loads, and other data, which are assumed constant (or averaged) throughout the calculation period. The calculation may be based on detailed or simplified physical assumptions or correlation methods. The other two calculation methods work with a typology of systems and/or subsystems and system-specific parameters. This means that either losses, auxiliary energy, or efficiencies are given as tabulated values for each subsystem or losses and efficiencies are given in tables for the entire space heating and/or domestic hot water system and appropriate values are selected according to the typology of the entire system.

The former two options are certainly too complex for our application. ÖNORM H 5056 (Austrian Standards Institute, 2011c) proposes a typology for subsystems and entire systems. Although, generally, actual data shall be used, a simplified calculation method is specified in ÖNORM H 5056 and in the OIB-handbook (Österreichisches Institut für Bautechnik, 2007a). For the simplified method, some assumptions are made for the most relevant cases, reducing the required input data by providing default values. Furthermore, the OIB-handbook defines 8 default systems giving all the necessary system details for the calculation of energy demand. For a detailed description see Annex I.

default technical building systems

1. Standard boiler (*Standardheizkessel*)
2. Low temperature boiler (*Niedertemperaturkessel*)
3. Condensing boiler (*Brennwertkessel*)
4. Combined heating and hot water by gas central heating (*Gaskombitherme*)
5. District heating (*Fernwärme*)
6. Single oven (*Einzelofen*)
7. Solar thermal system (thermische *Solaranlage*)
8. Heat pump (*Wärmepumpe*)

Since it is not feasible to provide complete and concrete details for all the technical features of the systems and subsystems, an overview of the minimum input parameters that need to be known to determine the energy demand for heating and hot water systems will be presented. We shall not refer to formulas, unless for illustrative purpose, as they can be looked up in the ÖNORM and EN standard. The calculation can be easily done with the aid of the calculation sheets provided by the Österreichisches Institut für Bautechnik.

Energy Demand Heating System

Monthly losses of the space heating system are calculated according to:

(4.36)

$Q_H = Q_{H,emission} + Q_{H,distribution} + Q_{H,storage} + Q_{H,generation}$ in case of a combined generation of hot water and space heating, $Q_{H,generation} = Q_{H,combined} \cdot r_H$ with $r_H = \dfrac{Q_{hw}}{Q_{hw} + Q_h}$.

heat emission

The calculation of thermal energy required for heat emission $Q_{H,emission}$ involves knowledge on the type of space heating emission systems installed in a building. The heating system can be either centralized for the whole building or decentralized, and hot water and space heat can be supplied by either a combined or separate system. Key input data is the type of heat emitter and the type of control equipment. Regarding heat emitters, the main types are radiators, convectors, or floor/wall/ceiling systems. As for the room space temperature, regulation the type of thermal control strategy (local, central, setback) and equipment (thermostatic radiator valve, P-controller, P-I-controller, PID controller, no control, etc.) and their ability to reduce temperature variations and drift must be known.

heat distribution

Thermal energy required for heat distribution $Q_{H,distribution}$ concerns mainly the linear thermal transmittance of the pipes and losses at the connections. Necessary input parameters are the dimensions of the pipes including the pipe length from the generator to the shafts, pipe length of the vertical shafts, pipe length of the connecting pipes, and the inner (without insulation) and outer diameter (with insulation). The type of pipe material, the insulation of pipes and taps, and the thermal conductivity of the insulation material are also relevant for determining losses due to heat distribution. Furthermore, the system temperatures are important for determining the mean heating circuit temperature per month and, thus, the temperature difference between the water in the pipes and the surrounding space.

Ideally, the calculation would consider all actual lengths, however, since dimensions of the pipes in existing buildings are not always known, ÖNORM EN 15316 and ÖNORM H 5056 provide for a simple method to calculate the length and diameter of pipes. Approximations of the pipes in a building or a zone are made based on the length and width of the building or zone, the floor height and the number of floors distinguishing between 3 types of pipes lengths:

- pipe length between generator and vertical shafts. These (horizontal) pipes can be laid in unheated spaces (e.g., basement, attic) or in heated space.
- pipe length in shafts. These (vertical) pipes are either laid in heated spaces, in outside-walls or in the inside of the building. The heating medium is always circulating.
- connection pipes. These pipes are flow controlled by the emission system in heated spaces.

Tab. 22: Default values outer diameter of heating pipes. (Austrian Standards Institute, 2011c)

Type of pipes		Length of pipes [m]
Horizontal distribution pipes for space heat		$7.5 + 0.048 \cdot A_f$
Vertical pipes for space heat in shafts		$0.1 \cdot A_f$
Connection pipes	small-area heat emitter (e.g., radiator, oven)	$0.7 \cdot A_f$
	large area heat emitter (e.g., floor, wall, ceiling heating system)	$0.35 \cdot A_f$

Source: ÖNORM H 5056

Tab. 23: Default values pipe length heat distribution in residential buildings. (Austrian Standards Institute, 2011c)

	Outer diameter for		
Type of pipes	$A_f < 250m^2$	$250m^2 \leq A_f < 1000m^2$	$A_f \geq 1000m^2$
Connection pipes	20 mm	20 mm	20 mm
Vertical pipes in shafts	20 mm	30 mm	40 mm
Horizontal distribution pipes	20 mm	50 mm	70 mm
Source: ÖNORM H 5056			

heat storage

The calculation of thermal energy required for heat storage $Q_{H,storage}$ involves information on whether the heating system is equipped with heat storage and information on the type of storage installed. Required input parameters are the date of installation [before 1978, 1978-1994, since 1994], the volume of the storage, and the type and number of [insulated, uninsulated] connections. The temperature difference between the operating temperature and the surrounding temperature in the zone is a determining factor for the amount of loss. Therefore, it is important to know whether the storage is installed in a conditioned or unconditioned space.

heat generation

Thermal energy required for heat generation $Q_{H,generation}$ depends on the type of heat generation, more precisely, on the type of heat generator and its efficiency. When the efficiency is not known, it can be approximated by distinguishing between different systems of different building periods. The heat generating device can be a boiler [standard boiler, low temperature boiler, condensing boiler, combined generation of heat and domestic hot water], but the heat can also be provided by an electrical heating, by district heating or another heat exchanger, and also by alternative systems: heat pump, of solar thermal system. Furthermore, the installation location [conditioned, unconditioned] and the operating mode [modulating or non modulating operation] are to be considered.

Energy Demand for Domestic Hot Water Heating

The energy demand for domestic warm water depends largely on user behaviour. Therefore, the Austrian standard defines the hot water demand in the user profiles.

$$Q_{DHW} = \frac{1}{1000} \cdot dhwd \cdot A_{ERA} \cdot d \tag{4.37}$$

$dhwd$ … domestic hot water demand for residential buildings according to ÖNORM B 8110-5 [35.0 Wh/(m^{2}d)]

A_{ERA} … energy reference area (0.8 x A_f) [m^2]

d … days per month [d/M]

The heat loss consists of the loss due to emission, to distribution, storage, and generation.

$Q_{HW} = Q_{HW,emission} + Q_{HW,distribution} + Q_{HW,storage} + Q_{HW,generation}$ in case of a combined generation of hot water and space heating, $Q_{HW,generation} = Q_{HW,combined} \cdot r_{HW}$ with

$$r_{HW} = \frac{Q_h}{Q_h + Q_{hw}}. \tag{4.38}$$

heat emission

Thermal energy required for heat emission $Q_{HW,emission}$ depends mainly on the hot water demand and on the type of tap [twin lever mixer tap, single lever tap]. The thermal energy required for heat distribution $Q_{HW,distribution}$ is calculated similar to the heat loss due to distribution of space heat. Important parameters for determining the linear transmittance of the pipes are the dimensions of the pipes (length, diameter), the pipe material (steel, copper, synthetic material, etc.), and the quality of the insulation. Since losses occur at the connections and fittings, a distinction is made between insulated and uninsulated connections. Information on the mean temperature of the water in the different pipes is needed for the calculation of heat losses.

heat storage

Regarding thermal energy required for heat storage $Q_{HW,storage}$ the type of storage [indirectly or directly heated warm water storage, directly gas heated warm water storage], the volume, the date of installation of the storage [before 1978, 1978-1986, 1986-1994, since 1994] as well as the location of installation are required parameters. And finally, the calculation of thermal energy required for heat generation $Q_{HW,generation}$ depends on the heat generator and generator efficiency. Mean efficiencies for the different heat generators can be looked up in tables.

Tab. 24: Default values for pipe length for hot water distribution. (Austrian Standards Institute, 2011c)

Type of pipes		Length of pipes [m]
distribution pipe; horizontal pipe between heat distribution and ascending pipe	with circulation	$7.0 + 0.013 \cdot A_{ERA}$
	without circulation	$7.0 + 0.013 \cdot A_{ERA}$
ascending pipe; vertical pipe between distribution pipe and stub or connection pipe	with circulation	$0.05 \cdot A_{ERA}$
	without circulation	$0.05 \cdot A_{ERA}$
circulation pipe; return pipe that ensures that distribution and ascending pipes are kept warm	distribution return pipe	$6.0 + 0.013 \cdot A_{ERA}$
	vertical return pipe	$0.05 \cdot A_{ERA}$
stub pipe; pipe between ascending pipe and tap	residential buildings	$0.20 \cdot A_{ERA}$

Source: ÖNORM H 5056

	Outer diameter for			
Type of pipes	$A_f < 250m^2$	$250m^2 \leq A_f < 1000m^2$	$1000m^2 \leq A_f < 10000m^2$	$A_f > 10000m^2$
stub pipe	20 mm	20 mm	20 mm	20 mm
ascending pipe	20 mm	30 mm	40 mm	55 mm
distribution pipe	20 mm	50 mm	70 mm	70 mm
circulation pipe	20 mm	20 mm	25 mm	25 mm

Source: ÖNORM H 5056

Tab. 25: Default values for pipe diameters for uninsulated pipes for hot water generation. (Austrian Standards Institute, 2011c)

Auxiliary Energy Demand

Auxiliary energy is electrical energy that is needed by technical building systems for heating and domestic hot water to operate the system (e.g., power supply for pumps, electrical control). The total auxiliary energy demand is the sum of auxiliary energy required for the heating system, the hot water system, and, eventually, the auxiliary energy needed for the heat pump or the solar thermal system.

$$Q_{aux} = Q_{H,aux} + Q_{HW,aux} + Q_{H,HP,aux} + Q_{Solar,aux} \quad (4.39)$$

Not all process steps require auxiliary energy. Whether auxiliary energy is required depends a lot on the system in use (cf. Tab. 26). To determine the following data have to be determined for each electrical device:

- electrical power consumption;
- duration of operation;
- part of the electrical energy converted to heat and emitted into the heated space.

Institut Wohnen und Umwelt (2005) has also developed a simple questionnaire for a rough assessment of the energy demand for heating and domestic hot water systems based on default values from different DIN standards. The required input parameters are reduced to as few as possible with the aim to use only parameters that don't require an on-site inspection. Therefore, system-typical efficiencies were assumed for different systems and subsystems for the generation of hot water and space heat. For the balancing, methods and formulas defined in the German DIN standards were applied. Beside some differences, e.g., regarding the use of expenditure factors as opposed to efficiencies for the calculation of losses related to the generation of heat, formulas are similar to the formulas in the ÖNORM standard. They are to be found in Institut Wohnen und Umwelt (2005) and will not be discussed here. However, some important differences concerning the default values exist with respect to the boundary conditions assumed. First of all, the German standard climate differs from the Austrian reference climate with regard to the annual mean external set-point temperature, the heating threshold temperature (DE: 15°C; AT: 12°C) and the length of the heating season (DE: 275 d/a; AT: 212 d/a). Also the operating hours of the systems are not identical.

The approach makes simplified assumptions regarding system temperatures and mean temperature of domestic hot water in the distribution pipes, the type of operation, and the operating hours. The building period classes are comparable to those proposed in the Austrian standard. The energy demand for domestic hot water is defined as 15.8 kWh per m^2 A_{ERA} heated floor space. The following energy fluxes are determined for each subsystem and all values are given per A_N[32] and A_{ERA}.

Analogously to the method adopted by ÖNORM H 5056, the calculation according to the Institut Wohnen und Umwelt (2005) is split into the subsystems emission, distribution, storage, and generation. However, the level of generalisation and direction of the approach is different. While the simple procedure according to the Austrian standard proposes a set of default systems with predefined system specifications which serve as input parameters for the calculation of energy losses and recoverable energy, the method of the Institut Wohnen und Umwelt takes the opposite approach. Departing from formulas and system-characteristic values defined in the DIN standards and derived from scientific studies, heat losses, recoverable heat, and auxiliary energy demand are calculated for

[32] A_N (*Gebäudenutzfläche*) is the energy reference area used in the German standards and in the context of the German Energy Saving Ordinance. It is not directly comparable to the energy reference area used in Austria and is determined as follows: $A_N = V_e \cdot 0.32/m$; to convert from A_N to A_{ERA}, A_N has to be multiplied by 1.25.

each subsystem for a number of varying assumptions and different combinations. Different assumptions are made concerning system specifications, building period categories, the number of m² A_{ERA} or A_N, and the number of full storeys and/or residential units. Out of the resulting matrix of values few system specific representative values are chosen, thus, the initial highly differentiated system specifications are gradually reduced to few system-specific variables.

Tab. 26: Parameters determined for each system and subsystem.

System	Subsystem	Expenditure factor	Parameters related to A_n and A_{ERA}		
			Heat loss	Recoverable heat	Auxiliary energy
Domestic hot water	Distribution		✓	✓	✓
	Storage		✓	✓	✓
	Generation	✓		✓	✓
Space heat	Emission		✓		
	Distribution		✓		✓
	Storage		✓		✓
	Generation	✓			✓
Conversion primary to final energy		✓			

Source: Institut Wohnen und Umwelt, 2005

Since all values are in one way or the other dependent on the dimensions of the building and/or the number of residential units (e.g., the boiler output, the length of the pipes, the required heat storage capacity) those factors had to be considered. The authors decided to eliminate the continuous variable "energy reference area" and refer the energy demand values only to the discrete parameters "number of full storeys" and "number of residential units" so that no interpolation is required. The number of full storeys [1-2, 3-5, >5] and number of residential units [1-2, 3-7, >7] were further grouped into classes so that in the end for each subsystem and parameter three energy demand values remained.

Once the system specific values for each sub-system were chosen, all subsystems are added up. Heat losses of technical systems, which count towards heat gains of the heating demand, are considered and the final energy demand for the heating system, the hot water system, and the auxiliary energy is converted into primary energy.

The required input parameters will be discussed in brief; the questionnaire can be found in the publication of the Institut Wohnen und Umwelt (2005).

heat distribution

To determine thermal energy required for heat distribution the method requires a distinction between central heating system and decentral heating system [room heating and single-storey heating system] as it has an implication on the length of the piping system. For the distribution of domestic hot water, the main distinction is between central hot water production with or without circulation pipe or with electrical trace heating and decentral hot water generation without circulation. For both systems, the building period class [1950-1979, 1980-1999, since 2000] serves as a proxy for the insulation standards of the pipes, however, it is possible to specify in the questionnaire a subsequent insulation of the pipes, e.g., as part of a rehabilitation.

Typical pipe lengths were not determined depending on the gross or net floor space, an approach chosen by the ÖNORM, but on the characteristic length L_{char} of the building, the number of storeys n_{ST}, and the height of the storeys h_{ST}. This method is more accurate since it considers the height of the building as well as the ground plan. For a simple rectangular ground plan, L_{char} is the same as the length of the rectangle. Three types of pipes for the distribution of space heat and hot water are distinguished:

Tab. 27: Pipe lengths for the distribution of space heat and hot water.

Type of pipes	Length of pipes [m]		
Space heat distribution			
	Horizontal pipes (pipe length between generator and vertical shafts)	Pipes in shafts (generally main vertical lines, but may also be horizontal)	Connection pipes (between vertical pipes and radiators)
Central distribution system with vertical shafts outside the thermal envelope	$4L_{char} - 10$	$n_{ST} \cdot L_{char}$	$\frac{3}{2} n_{ST} \cdot L_{char}$
Central distribution system with vertical shafts inside the thermal envelope	$2L_{char} - 10$	$\frac{n_{ST} \cdot L_{char}}{2}$	$4n_{ST} \cdot L_{char}$
Distribution per apartment	–	$6n_{ST} \cdot L_{char}$	$n_{ST} \cdot L_{char}$
Distribution domestic hot water			
	Horizontal pipes (pipe length between generator and vertical shafts)	Pipes in shafts (generally main vertical lines, but may also be horizontal)	Stub pipes (between vertical pipes and taps)
Central hot water production with circulation pipe	$2L_{char} - 10$	$\frac{n_{ST} \cdot L_{char}}{2}$	$\frac{n_{ST} \cdot L_{char}}{2}$
Central hot water production without circulation pipe	$L_{char} - 5$	$\frac{n_{ST} \cdot L_{char}}{4}$	$\frac{n_{ST} \cdot L_{char}}{2}$
Central hot water production with electrical trace heating	$L_{char} - 5$	$\frac{n_{ST} \cdot L_{char}}{4}$	$\frac{n_{ST} \cdot L_{char}}{2}$
Decentral hot water production without circulation pipe	–	–	$\frac{n_{ST} \cdot L_{char}}{2}$

Source: Institut Wohnen und Umwelt, 2005

heat storage

Input parameter for determining thermal energy required for heat storage are the type of hot water storage [combination boiler = indirectly heated storage, central gas-fired small cylinder, (central) electric water cylinder]. The building period class serves as proxy for a combined central heating outside the thermal envelope [until 1994] or inside the thermal envelope [since 1995]. For the storage of heat, two representative systems were defined: a 200 litre cylinder for an electric heat pump and an 800 litre buffer storage tank for a wood-fired boiler.

hot water generation

In terms of thermal energy required for hot water generation six different systems are distinguished: combined heating and hot water generation (cf. heat generation), central gas-fired water storage heater, electric heat pump, district or local heating, thermal solar system, and decentral system (electric instantaneous water heater and decentral gas-fired instantaneous water heater). For a central system, important additional information for the estimation of insulation standards is the year of manufacture resp. year of installation of the system.

Regarding heat generation for the heating system, the single most important distinction is between central and decentral heating system. For a central heating system, three main types of heaters are distinguished: boilers or cylinders, electric heat pumps, and district or local heating.

With regard to boilers, required input parameters are the type of fuel [natural gas/liquid gas, oil, fire wood or wood pellets], which is needed for the conversion from final energy to primary energy, and the year of manufacture of the boiler or cylinder [until 1986, 1987-1994, since 1995]. For gas and oil-fired boilers an additional distinction is made between constant and gliding water temperature. Boilers with gliding water temperature provide just enough heat to reach the required boiler temperature for each outside temperature and therefore have lower losses, usually the case in low temperature and condensing boilers. On the other hand, boilers with constant water temperature provide always the same amount of heat (70-90°C), which is generally the case in standard boilers and constant temperature boilers. Another aspect considered is the heat recovery from water vapour in the hot flue gas, a technology used in condensing boilers, which increases the boiler efficiency.

For electric heat pumps, a differentiation is made between heat pumps with and without heating coil, heat pumps in combination with a boiler, and the single heating element. Furthermore, the heat source must be specified [air to air or air to water heat pump, ground source heat pump] as well as the year of manufacture of the electric heat pump.

For district heating, the type of generation [boiler/heater, cogeneration] and the share of heat from combined heat and power generation are required. For decentral heating systems, which can be either single storey heating or room heating, the type of system [gas single-storey heating system with or without recovered latent heat from water vapour in the flue gas, gas heating, single oven, electric heater or electric night storage heating] and the year of installation must be stated. For the single oven, the type of fuel [oil, coal, fire wood] is asked.

heat emission

Concerning thermal energy required for heat emission, default values are assumed, more specifically, for thermally controlled heating systems q=3.3 kWh/(m²·a) for A_N and q=4.1 kWh/(m²·a) for A_{ERA}.

Energy Demand for Lighting

The contribution of energy demand for illumination is rather small compared to the total energy demand for electricity and heat in a residential building. Therefore, it is not assessed for residential buildings as part of the energy performance calculation defined in ÖNORM H 5055 (Austrian Standards Institute, 2008e). For all other types of buildings, ÖNORM H 5059 (Austrian Standards Institute, 2008f) defines the framework, while the method as such is specified in ÖNORM EN 15193 (Austrian Standards Institute, 2010). However, lighting is linked to floor space per resident and omitting the energy demand for lighting would mean to omit an important aspect of energy demand related to land use planning.

The energy requirements of lighting in buildings depend on a number of factors:

user behaviour

- user behaviour: the annual operating time of each lamp is very much related to personal preferences and habits. Therefore, the operating hours, split into daylight time usage t_D and nighttime usage t_N, are defined in ÖNORM B 8110-5 for the different building categories. The standard operating hours during the daylight time in a room or zone can be reduced by daylight availability in the room or zone or a reduced occupancy period; that of night time operating hours by reduced "occupancy" of a room or zone. Daylight supply is determined, similar to solar gains, according to the geographic location or obstruction. These dependencies are expressed by dependency values. Another dependency value, F_O, factors in the difference between light sources in a room or zone that are all switched on manually or automatically at once or light source in a room or zone that are switched on individually.

lighting power

- lighting power installed: the total lighting power depends on the number of luminaires installed and on the luminous efficacy of each light source, expressed in lumen per Watt. A standard filament lamp requires more power for the same luminous flux than a halogen lamp or a fluorescence lamp. Values can be obtained from manufacturers and default values for different types of light sources are included in the calculation sheet for non-residential buildings provided by the OIB. Furthermore, it depends on the operating efficiency of the luminaire; default values are also given in the OIB calculation sheet. The lighting power required can be reduced by a lighting control system in combination with a dimmable lighting system that compensates the reduced output of lighting installations which happens over time, expressed by the constant luminance factor F_C.

annual parasitic energy

- annual parasitic energy: energy required to provide charging energy for emergency lightning and for standby energy for lightning controls in the building.

The total annual energy used for lightning is defined as the sum of the annual lightning energy and annual parasitic energy. To compare buildings that have similar functions, but are of different size and configuration, the LENI-factor [kWh/a], a numeric indicator of the total annual lighting energy required in a building, was introduced.

LENI-factor

$$LENI = W / A_{useful} \tag{4.40}$$

$LENI$ … lightning energy numeric indicator [kWh/(m²·a)]
W … total annual energy used for lighting [kWh/a]
A_{useful} … total useful floor area of the building [m²]

4.3.3 Calculating the Primary Energy Demand of Buildings

THE PREVIOUS SUB-CHAPTER discussed methods and minimum requirements regarding input parameters for the calculation of energy demand of buildings. In this chapter, we will describe how these methods can be applied to a settlement or municipality and what kind of data sources are available.

4.3.3.1 Data Sources

The Austrian Statistical Office stores a large amount of building data. Comprehensive data on existing buildings used to be collected every 10 years as part of the Austrian population and building census and selected data were collected in additional microcensus

Data sources:	Data owner	Cover-age	Data	Year
Gebäude- und Wohnungsregister	Statistik Austria	Austria	Building and building address: dimensions and structural features Utilization units and address of units: size and features of floor space and floor space utilisation	2004 to date
Gebäude- und Wohnungszählung	Statistik Austria	Austria	Data on the building stock and existing floor space	1991/ 2001
Wohnbaustatistik	Statistik Austria	Austria	Data on utilization units (dwellings, mixed use dwelling/working)	2003
Digitale Katastermappe / Grundstücksdatenbank	Bundesamt für Eich- und Vermessungswesen (BEV)	Austria	Land registry, location and boundary of properties, and different land uses including buildings	1995; regular update
Aerial photos	BEV, Bundesländer	Austria	True colour orthophotos with ground resolution 20-25 cm; M 1:15.000	1989-2010
Austrian reference climate	Central Institute for Meteorology and Geodynamics	Austria	Monthly average temperature, solar irradiance,	1971-2000

Tab. 28: Data sources.

surveys. A second important statistic is the residential building statistic, a survey on construction activities in the residential building sector. Due to new requirements arising from the Council Regulation (EC) No 1165/98 on short-term business statistics to deliver quarterly reports on building permits (number of new residential buildings and square meters of useful floor area) to EUROSTAT as economic indicator, the statistical office was forced to develop a new system on data collection for the Austrian building stock. In 2004, a new database system, the so-called "Adress-GWR" (address-, building, and housing register), was introduced. It replaced the old system of direct surveys of building related data by placing the task and responsibility of data collection into the hand of the municipalities which access the database and update data on-line. The central statistical data record is the building and the building's address. The EUROSTAT definition of building[33] was adopted which defines a building as a "a roofed construction which can be used separately, has been built for permanent purposes, can be entered by persons and is suitable or intended for protecting persons, animals or objects." Furthermore, the building must occupy an area > 20m^2 and in the case of interconnected structures (e.g., semi-detached or terraced houses), any unit separated from other units by a fire wall extending from roof to cellar is considered an individual building. The interconnected building may also be regarded as more than one individual building unit, in spite of a lacking, separating fire wall, if the units have their own access (own entrance) as well as their own utility system and are separately usable. This means that in practice, in large residential housing estates or apartment blocks each staircase or terraced house is counted as a separate entity.

address, building, and housing register

Generally, buildings in the Adress-GWR database are classified according to the EU classification of types of constructions into 11–residential and 12–non-residential buildings and are assigned to a main building type [111–one-dwelling residential buildings, 112–two and more dwellings residential buildings, 113–residences for communities, 121–hotels and similar buildings, 122–office buildings, 123–wholesale and retail trade buildings, 124–traffic and communication buildings (including 1274–garage buildings),

EU classification of types of constructions

[33] Definition taken from: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Building [accessed on 29 November 2011]

125–industrial buildings and warehouses, 126–public entertainment, education, hospital or institutional care buildings, 127–other non-residential buildings (including 1271–non-residential farm buildings, 1272–buildings used as places of worship and for religious activities, 1274–other buildings not elsewhere classified)]. The allocation is done automatically by the system according to allocation rules: a building is classified into residential building if at least half of it is used for residential purposes. If less than half of the overall useful floor area is used for residential purposes, the building is classified according to its main use. The main use is determined according to the building use or purpose with the largest percentage of the overall useful area, excluding garages and uninhabited basements and attics.

utilisation units

Each building must be split into one or several utilisation units following a general classification into "dwelling" and "other utilisation units". According to EUROSTAT[34] "a dwelling is a room or suite of rooms - including its accessories, lobbies and corridors - in a permanent building or a structurally separated part thereof which […] is designed for habitation by one private household all year round."

building uses

Each utilisation unit must be assigned to one of 17 different building uses [1–floor space for dwelling, 2–mixed use living and working, 3–shared living, 4–hotels or similar, 5–offices or administration, 6–wholesale and retail, 7–traffic and communication, 8–industry and warehouses, 9–culture, leisure, education, healthcare, 10–agricultural use, 11-private garage, 12–church or other sacred building, 13–pseudo building (temporary buildings such as caravans, barracks, etc.), 14–other building, 15–(uninhabited) attic, 16–(uninhabited) basement, 17– thoroughfares (access and circulation areas, areas of stairwells, lifts, escalators)].

on the level of the utilisation unit

For each utilisation unit the following features must be specified:

- Address of the utilisation unit including the number of storeys of the utilisation unit and where in the building (on which floor/s) the utilisation unit is situated.
- Number of residents (main and secondary residence)
- Specific use (cf. building uses)
- Net floor space or useful floor area per utilization unit [m^2]
- Number of rooms; this information is mandatory for the uses "living and mixed use living and working", rooms > $4m^2$ must not be counted.
- Average room height (clear height) [m]
- Furnishing (bath, toilet, kitchen/kitchenette, water connection)
- Ownership
- Heating system (type of fuel, type of heat emission, etc.; see "building")
- Hot water preparation system (see "building")
- Ventilation (see "building")
- Energy performance indicator according to energy performance certificate

Each building and utilization unit must have an address. The address contains information on the cadastral municipality, municipality, village, name of the street and house number, property parcel number, information on the suitability of the building for dwelling as well as a GIS-coordinate. Most of the features of the address are pre-defined by

[34] Definition taken from: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Dwelling [accessed on 29 November 2011]

the database system including some features of the building which are automatically assigned (e.g., the number of residents which are registered at a given address or the building type). Regarding floor space management, the terms used are in concordance with terms defined in ÖNORM B 1800. Net floor areas are only reported on the level of utilisation units. Total net floor space and net floor space per storey are calculated automatically. Gross floor areas are recorded on the level of storeys and the total gross floor space is again a calculated value. All area data are recorded with an accuracy of two decimal places.

on the level of the building

On the level of the building the following features are mandatory:

- Building class according to EUROSTAT
- Suitability for dwelling is set to YES if the building is used as dwelling or mixed use dwelling/working. [yes/no]
- Building period/year of construction/building date. The building period is the period in which the building was constructed whereas the building date is the date when the building was used according to its intended purpose; while the information on the building period is mandatory, the building date is optional for buildings constructed before 2004. [before 1919, 1919-1944, 1945-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001, …, 2011]
- Building height as the height difference between to highest point of the building envelope and the lowest point of the terrain directly bordering the building. [m]
- Gross volume is defined according to ÖNORM B 1800 as the volume which is delineated by the building envelope and the bottom edge of the bottom plate of the building. [m^3]
- Built-up area is defined according to ÖNORM B 1800 as the area delineated by the perpendicular projection of the outermost contour line of the gross floor space of the building. [m^2]
- Built up area according to BEV is the area of the ground plan of the building according to the digital cadastre; the value is imported directly from the cadastre and cannot be changed. [m^2]
- Gross ground plan of the building is the sum of all ground plan surfaces. In practice, the value recorded in the registry is calculated as the mean value of the sum of gross floor space per storey. [m^2]
- Gross floor space per storey according to ÖNORM B 1800 is the area delineated by the outer dimensions of the storey. [m^2]
- Net floor space of the building recorded in the registry is calculated as the mean value of the sum of net floor space per storey. [m^2]
- Net floor space per storey is calculated from the net or useful floor space per utilisation unit that are located on the respective floor and can only be changed on the level of utilisation units. [m^2]
- Number of storeys above ground is defined as the number of storeys with more than half of the storey height above the surrounding terrain. An intermediate floor (e.g., mezzanine) counts as a separate storey if it is offset against the other storeys by at least half of the storey height.
- Number of storeys below ground is defined as the number of storeys with more than half of the storey height below the surrounding terrain (e.g., basement, souterrain).
- Height of the storey is defined as the (mean) distance between the top edge of the

floor and the top edge of the floor of the next storey above. In case the attic is part of the useful floor space, the top edge is defined as the outer edge of the roof cladding. [m]
- Construction type per storey [concrete or masonry construction, reinforced concrete, steel skeleton, light-frame construction (load-bearing structure is made of timber beam framing)]

optional parameters

Some features are optional input parameters:
- Ownership
- Sewer connection [connection to the public sewer system, small sewage treatment plant, collecting pit, unknown]
- Water connection [municipal water supply, private water well, unknown]
- Electricity connection [connection to power supply, off grid supply, unknown]
- Gas connection [connection to gas mains, no connection, unknown]
- Rain water discharge [onto the ground, into sewer system, into water body, unknown]
- Waste disposal [municipal waste collection, own disposal, unknown]
- Type of heating [central heating for building, decentral heating (room heating, single storey heating)]
- Heating system [boiler, standard boiler, low temperature boiler, condensing boiler, heat pump (air-to-water, ground-to water, water-to-water, others), thermal solar system, local heating/heat-only boiler station, district heating, room heating, other heating systems]
- Operation mode [modulated=controllable boiler output, non modulated, monovalent=central heat supply by heat pump, bivalent=heat supply by heat pump with supplementary system]
- Type of fuel [extra light heating oil, light heating oil, natural gas, liquid gas, local and district heating, coal, fire wood, wood chips, wood pellets, other biomass, electricity, other fuel]
- Heat emission system [radiators/convectors, floor/wall/ceiling system, air heating system, convector heater/fan coil]
- Type of hot water system [central system (one system supplies the whole building; e.g., boiler, local or district heating), decentral system (one system supplies the utilisation unit, e.g., gas or electric boiler, instantaneous water heater)]
- Hot water generation [combined heat and hot water, separate heat and hot water, solar thermal system combined with heating system, electric heating coil, etc.]
- Ventilation [natural ventilation, mechanical ventilation, exhaust air system, supply and return air system with heat recovery or without heat recovery, HVAC-heating, ventilation, and air conditioning]
- Energy performance indicator according to energy performance certificate
- Elevator [yes/no]

The data base was pre-filled with existing data from the building census 2001, the administrative building registry 2001, the residential building statistic 2003 as well as with data from the Austrian Federal Office of Metrology and Surveying (BEV) and the Central Register of Residents (ZMR). The latter two provided address data of buildings and utilization units. The Federal Office of Metrology and Surveying also provided the official property parcel numbers and the GIS-coordinate of the building which is placed at the main entrance of the building. An automatic synchronisation between ZMR and Adress-GWR is executed on a routine basis every month.

Most data of the initial filling of the database come from the building census 2001, for buildings classified as "dwelling" or "mixed use dwelling and working" the more recent data from the residential building statistic 2003 were used. Buildings that could not be allocated to one of the utilization units were pre-filled with default values and structural feature were set to "unknown".

Beside data on the building stock and addresses, several structural features were imported from the sources mentioned. Data on the built up area could be determined by means of the digital cadastral map in two thirds of all cases. For the remaining third the built up area either referred to data from the building census or it was approximated with data on floor space from the residential statistics or a default values of 20 m^2 was set. Gross floor space was calculated as the product of built-up area times the number of storeys unless an actual value from the residential building statistic was available. Regarding the number of storeys, the database was filled with data from the building census or the residential building statistic for residential buildings. For all non-residential buildings a default value of one storey was assumed. Information on the square meters net or usable floor space was retrieved from the building census 2001 or the residential building statistic 2003. Primary source for the building period were the building registry 1991 and the residential building statistic 2001. Information on the connection of the building to gas mains, sewerage, municipal water supply and on the type of heating were adopted from the building registry 2001 or, if available, taken from the residential building statistic or set to "unknown". The same is true for heating demand, which was filled with data from the residential building statistic, if available, or set to "unknown".

Despite the availability of large amounts of building data their use is severely limited due to legal restrictions on data retrieval. The Austrian Statistical Office and the municipalities (in their domain) have the possibility to generate customized reports and statistics. However, for reasons of data privacy, reports which contain data on individual buildings are not passed on to third parties and data are only provided in aggregated format. This means that 1-to-1 assignments of data on net floor space, number of storeys, building period, construction type and ground plan type, all of which are minimum requirements for calculating building energy demand, are not possible. Available workarounds or solutions involve the evaluation and subsequent classification of data, particularly of data which are not integers such as the gross or net conditioned ground floor. However, we must bear in mind that any workaround to the use of highly disaggregated building data must be associated with compromises regarding the accuracy of results. Blanket assumptions have to be made regarding the ground plan type, the number of directly adjacent buildings, the shape of the roof and whether a building has a conditioned or partially conditioned basement or attic.

Austrian Digital Cadastral Map (DKM)

A second important source of information are geographic data such as the Austrian Digital Cadastral Map (DKM) and geometrically corrected aerial photos, so-called orthoimages. The digital cadastral map is the graphical representation of the land registry and is kept and updated by the land surveying offices in each district. It is based on the old cadastral maps, which date from the period 1989 to 2005 and were kept in analogue form, and on stored coordinates. Therefore, the accuracy of the digital cadastral map corresponds with the accuracy of the analogue maps, while the degree of actuality is permanently improved by updating the map with data from the land registry, surveying campaigns, remote sensing, etc. Main content of the map is the exact location and boundary of properties and the property parcel number. Furthermore, it also contains the boundaries of different land uses such as forest, agricultural land, traffic areas, etc., as well as the ground plan of buildings. Information on the location and extent of buildings can either come from land surveying or from digitalised orthorectified aerial photos. Information on the source of the GIS-object is stored in the layerfile.

An orthophoto is an aerial photograph which was geometrically corrected ("orthorectified"), thus, adjusted for topographic relief, lens distortion, and camera tilt, such that it can be used to measure true distances. Orthophotos are produced in black and white, true or false colour. Until 2010 aerial mapping was carried out using analogue cameras which produced images with a ground resolution of 25 cm. Since the use of digital cameras, the resolution was improved to 20 cm pixel size for colour orthophotos. Aerial surveying flight campaigns shall take place in regular cycles of 3 years; however, the actual year of production of each map sheet can be inquired on-line on the web-site of BEV. Apart from the Federal Office of Metrology and Surveying most *Bundesländer* also conduct flight campaigns and produce their own imagery.

4.3.3.2 Boundary Conditions

With regard to climate boundary conditions for the calculation of heating demand, it makes sense, for comparability of results, to use the Austrian reference climate instead of the local climate conditions. It defines the monthly mean temperature and mean solar irradiance, as well as the solar irradiance according to orientation (cf. ÖNORM B 8110-5 Annex A, Table A.1).
The number of heating degrees days for the reference climate is determined according to the formula

$$HDD_{20/12} = \sum_i \left(\theta_{i,h} - \theta_{e,i}\right) \cdot d_i \text{ with } \theta_{i,h} = 20°\text{C}.$$

Determining monthly heating degrees days							
	January	*February*	*March*	*April*	*Mai*	*June*	*SUM*
I_S [kWh/m²]	29.79	51.42	83.40	112.81	153.36	155.22	
d_i	31	28	31	30	31	30	
$\theta_{e,i}$ [°C]	-1.53	0.73	4.81	9.62	14.20	17.33	
$\theta_{i,h} - \theta_{e,i}$ if <12°C	21.53	19.27	15.19	10.38	0	0	
$HDD_{20/12}$ per month	667.4	539.56	470.9	311.4	0	0	1989 Kd

Tab. 29: Austrian reference climate.

As defined in the system boundaries, this study's focus is restricted to those aspects of energy demand which are supposed to be influenced by land use and spatial patterns and can be attributed to households. Industry's and companies' energy demand may also be

Determining monthly heating degrees days							
	July	*August*	*September*	*October*	*November*	*December*	
I_S [kWh/m²]	160.58	138.50	98.97	64.35	31.46	22.33	
d_i	31	31	30	31	30	31	
$\theta_{e,i}$ [°C]	19.12	18.56	15.03	9.64	4.16	0.19	
$\theta_{i,h} - \theta_{e,i}$ if <12°C	0	0	0	10.36	15.84	19.81	
$HDD_{20/12}$ per month	0	0	0	321.16	475.2	614.11	1410 Kd
$HDD_{20/12}$ per year							3400 Kd

Source: ÖNORM B 8110-5 (Austrian Standards Institute, 2011a)

affected by land use but remain outside the defined system boundary as they have very distinct energy consumption patterns. For this reason, only buildings classified as "residential buildings", including 'one-dwelling residential buildings', 'two and more dwellings residential buildings', 'residences for communities' will be considered in the assessment. However, it is important to note that also buildings classified as non-residential buildings may accommodate a dwelling and that a residential building may have floor space used for other purpose than dwelling. Therefore, alternatively, the assessment could be carried out on the level of utilization units which would yield a more accurate result yet also complicate the calculation process. In this case, the building uses "floor space for dwelling", "mixed use living and working", and "shared living" are taken into consideration.

Regarding standardized specifications of the annual use of residential buildings, user profiles defined in ÖNORM B 8110-5 will be applied. Provided buildings are treated according to their main use, it seems appropriate to treat them as a single zone assuming the same room temperature conditions throughout the building. By the same token, the types of thermal transfer considered are heat transfer between conditioned space and the external air, puffer spaces (e.g., unconditioned, closed rooms) and building elements with immediate ground contact, while the case of heat transfer between two conditioned zones with different set-point temperatures is ruled out.

Tab. 30: Temperature correction factors according to ÖNORM B 8110-6 and Institut Wohnen und Umwelt.

Type of heat transfer	f_i from ÖNORM B 8110-6	f_i from Institut Wohnen und Umwelt
Transmission to the external environment		
e.g., external wall, roof area, topmost ceiling	1.00	1.00
Transmission to unconditioned spaces (puffer space)		
to unconditioned attic	0.90	1.00
to garage	0.9	
to conservatory		
- single glazing	0.80	
- insulating glass	0.70	
- heat-reflecting glass	0.60	
to uninsulated basement	0.70	1.00
to insulated basement	0.50	1.00
to other puffer spaces	0.70	

Type of heat transfer	f_i from ÖNORM B 8110-6	f_i from Institut Wohnen und Umwelt
Transmission to the ground		
wall to ground	0.70	0.60
floor to ground	0.60	0.60
Source: ÖNORM B 8110-6 and Institut Wohnen und Umwelt, 2005		

Knowing the dimensions and geometry of a building is essential, particularly, for the calculation of transmission losses. In the previous chapter, two approaches were presented for estimating a building's dimensions: the simplified, but conventional approach in accordance with ÖNORM B 8110-6 (Austrian Standards Institute, 2011b) and the estimation of surface areas by means of correlation parameters proposed by the Institut Wohnen und Umwelt (Institut Wohnen und Umwelt, 2005). In principle, both approaches can be pursued for the purpose of this study, although the latter bears the advantage of being independent from knowledge on the length and width of the building. According to the method defined in ÖNORM B 8110-6, length and width of the building, together with the building height, are indispensable for determining the surface areas of the facade elements of the thermal envelope.

The central variable in the statistical method is the conditioned net floor space or useful floor space, A_{ERA}, or more precisely, the useful floor space per storey, $A_{ERA/ST}$, while the ÖNORM method generally refers to the gross floor space, A_f. In both approaches A_{ERA} can be derived from A_f, or from the gross ground plan A_{GB}. All values, including the floor space per storey, can be found in the Adress-GWR database; however, only $A_{ERA/ST}$ and $A_{f/ST}$ are directly entered into the database while the other values are calculated. The completest data record is that on the built up area taken from the digital cadastral map referring to the area of the ground plan of the building. However, it also includes adjoining buildings such as garages, etc. If no other value is available the gross floor space can be calculated by multiplying the built up area with the number of storeys.

The number of storeys and height of the storeys is essential information which is also stored in the database. For the statistical approach, the clear height of rooms is required; a value, which is not included in the database. Possible solutions are to use the default value of 2.5 m proposed in the method or to subtract 0.5 m for the slab thickness from the storey height. Information on the use of attics and basement for living, in order to know whether they are part of the conditioned space, is difficult to extract from the database. It can only be analyzed on the level of utilization units by looking at the location of the unit in the building. The conditioned gross volume can be either calculated according to the formula ground plan x storey height x number of storeys or directly obtained from the database.

Some input information must be derived from aerial images such as the building type and number of directly adjacent buildings or the ground plan type. While ÖNORM B 8110-6 distinguishes between five types of horizontal projections, rectangular, L-, T- U-, or O-shape, the method of the Institut Wohnen und Umwelt differentiates only between compact and elongated ground plan. Dowers and other roof structures, as required in the statistical approach, can be discerned on aerial views while projections and recesses, which are included in the ÖNORM approach, are more difficult to recognize on aerial views.

Determining the surface area of transparent building elements without additional site visit is difficult. The Adress-GWR database does not provide information on this parameter. The method of Institut Wohnen und Umwelt allows the estimation of the window area by means of statistical correlation with the useful floor space. Transparent building elements other than windows, e.g., glass facades, conservatories, etc., are not covered by this approach.

To summarise, the method for estimating the building geometry based on correlation with the net floor space is more practicable than the ÖNORM approach and provides sufficiently accurate results for an assessment such as this, which aims at comparing and not at gaining exact values of the energy performance of the buildings of a settlement.

4.3.3.3 Heating Demand

Determining the heating demand of a building involves calculating transmission and ventilation heat losses as well as internal and solar gains. The calculation procedures defined by the European, Austrian and German standard are similar and require the same input parameters:

- the surface area of the thermal envelope
  - area opaque building elements
    - basement ceiling, topmost ceiling, external wall, roof area, outer doors
      - U-value of each building element
      - heat transfer coefficient
  - area transparent/glazed building elements
    - window area, glass façade
      - orientation of each transparent building element
      - shading of each transparent building element
      - g-value of each transparent building element
- the energy reference area
  - useful floor space
  - gross conditioned floor space
- the local climate conditions
  - annual (local) heating requirement
    - heating degrees days
    - monthly mean exterior temperature
  - intensity of solar radiation

transmission heat loss

Surface parameters were already determined as part of the building geometry and heating requirements were established in the course of defining the reference climate conditions. Once these boundary conditions are fixed the heat transmittance, or U-value, of the individual building elements has to be determined. The heat transmittance is the most important input parameter for the calculation of a building's total transmission heat loss. For an accurate U-value, detailed information on the construction type of the building element and on the material and thickness of each layer of the thermal insulation are required in order to mathematically determine the value or to correctly refer to values published by accredited testing laboratories for certified building components. However, this procedure is neither possible nor is this high level of detail required for the purpose of assessing the heating demand of settlements; the use of default values yields a sufficiently accurate result. Default or benchmark values for building elements are published in the handbook of the OIB for each *Bundesland*. A problem associated with the use of these values is the issue of comparability. First of all, values differ greatly due to the lack of harmonized insulation standards in Austria since they are defined autonomously by each *Bundesland* in the respective building regulations and were/are sometimes coupled with the residential construction subsidisation, meaning that housing construction financed without governmental subsidies was not bound by these standards. Secondly, the limited comparability is related to the fact that U-values were defined for a different time frame and for different time intervals. While Carinthia and Lower Austria have revised their insulation standards every couple of years, Burgenland has adjusted its benchmarks only two times since 1988. These U-values are therefore unsuitable for the purpose of comparing the energy demand of buildings in different provinces of Austria.

The German Institut Wohnen und Umwelt, as part of their simple method for the calculation of heating energy demand, proposes a set of default values for heat transmittance which require a differentiation between construction type and building period. With respect to "construction type", a simple distinction is made between a massive construction and a wooden construction because structures built as lightweight construction generally have a lower U-value. Both input parameters, the building period and the type of construction, are documented in the Adress-GWR database. The construction type is recorded per storey and can be easily matched with the classification into massive construction (concrete or masonry construction, reinforced concrete, steel skeleton) and light construction (light-frame construction). However, a separate allocation of the construction type to the building elements "façade", "topmost" and "bottommost surface of the building envelope" and "roof" is not possible, which is why a uniform construction type for the whole building has to be assumed. Another problem associated with the use of these default U-values is the fact that building periods do not match with the building periods recorded in the building registry. Therefore, it might be necessary to adopt the default heat transmittance values to the Austrian situation.

Since the U-value of a building's thermal envelope after thermal rehabilitation can deviate considerably from the characteristic U-values of the construction period of the building the effect of additional insulation must be taken into account in the calculation. The effect depends very much on the thickness of additional insulation and on the extent of the thermal renovation in percent of total area of each building element which is why they are is necessary input parameter. Information on additional structural alterations of a building is not recorded in the Adress-GWR database. However, information on structural alterations, such as a new covering of the roof, a renewal of windows, installation of central heating, facade renewal including thermal rehabilitation, or connection to the sewer system were gathered in the last building census 2001 and are available per municipality in aggregated form in percent and absolute numbers.

Both approaches consider geometric thermal bridges by adding a heat transfer coefficient for linear (and point) thermal transmittance. The coefficient depends on the total area of the thermal envelope, the U-value of the building element, and the temperature correction factor for the building element. That means that no information other than the input parameters for determining losses due to thermal transmittance is required.

ventilation heat loss

Regarding ventilation heat losses natural ventilation is assumed for residential buildings. Since air exchange depends largely on user behaviour and on the air tightness of the building, the air exchange rate is standardised for reasons of comparability. The ÖNORM defines the air exchange rate as 0.4 h^{-1} and the Institut Wohnen und Umwelt assumes a rate of 0.6 h^{-1}. In the case of a pre-defined heat exchange rate, the heat transfer due to ventilation depends only on the conditioned air volume and on the local climate conditions. The conditioned air volume can be either calculated according to the formula $V_V = A_{ERA} \cdot 2.5m$ (Institut Wohnen und Umwelt, 2005) or the formula $V_V = 0.8 \cdot A_f \cdot 2.6$ (Austrian Standards Institute, 2011b).

solar gains

In terms of the positive fluxes, the calculation of solar gains depends very much on the (solar effective) area of the glazed façade elements and on the intensity of solar radiation in a particular location, in other words, the solar irradiance. The average solar irradiance is defined for different climate zones, altitudes, and orientations and also for the reference climate. The solar effective area is the area of the glazed façade elements reduced by permanent shadings, which is expressed by the shading reduction factor and by the limited permeability of transparent surfaces, expressed by the g-value. Unless a site inspection is possible, the window area of a building façade must be determined according to the estimation method developed by the Institut Wohnen und Umwelt. Default values are defined in ÖNORM B 8110-6 for the shading reduction factor (ÖNORM: 0.85; Institut Wohnen und Umwelt: 0.60) and for g-values for different types of glass. However, default g-values provided by the ÖNORM require a detailed differentiation between types of glass and window frames. The Institut Wohnen und Umwelt also provides default g-values for different window types distinguishing between the categories "wooden windows with single glazing", "wooden windows with double glazing" and "insulating glass with plastic", "insulating glass with aluminium or steel frame". Finding out whether the glazing is made of insulating glass would require an on-site inspection. To avoid this step, the authors made use of the fact that since the introduction of the thermal insulation regulation in Germany in 1995 the use of insulating glass has increased sharply. Therefore, the date of the installation of the window is used as a proxy.

The actually exploitable solar radiation depends not only on the local intensity of solar radiation but also very much on the orientation of the building; especially, on the orientation of the windows. The orientation of windows is difficult to assess without site inspection. Therefore, the statistical method assumes a default east-west orientation of the windows.

Tab. 31: Reference solar irradiance for east-west facing windows. (Austrian Standards Institute, 2011a)

Reference solar irradiance for orientation east-west						
	January	*February*	*March*	*April*	*Mai*	*June*
I_S [kWh/m²]	19.51	32.14	52.12	67.68	88.18	88.48
	July	*August*	*September*	*October*	*November*	*December*
I_S [kWh/m²]	93.14	81.71	60.37	40.86	20.14	14.63
Source: ÖNORM B 8110-5						

internal heat gains

Given the small contribution of internal heat gains to total heat gains in residential buildings, both the ÖNORM and the statistical approach developed by the Institut Wohnen und Umwelt use a default value for the heat flux from internal heat sources. The Austrian default value for $q_{i,h,n}$ = 3.75 W/m² per day for residential buildings during the heating season, while the German Energiesparverordnung estimates Q_i to be 22 kWh/m²$_{ERA}$/a. The values are not readily comparable, first of all, because the Austrian standard gives a daily value while the German regulation defines an annual value, secondly, because the energy reference area is defined differently and the length of the heating season is not identical in the two approaches. Whichever default heat flux is chosen, in both approaches internal heat gains depend only on the size of the energy reference area.

total heating demand

Once transmission and ventilation heat losses and internal and solar gains are determined, the total heating demand is calculated according to formula

$$Q_h = \sum_i f_p \left(\left(Q_{T_i} + Q_{V_i} \right) - \eta \cdot \left(Q_{I_i} + Q_{S_i} \right) \right) \text{ in [kWh/a].}$$

Since we are interested in the per capita consumption, Q_h finally has to be divided by the number of residents.

The Austrian Institut für Bautechnik has developed a calculation sheet which facilitates the calculation procedure with the disadvantage, however, that the sheet is locked and cannot be modified to e.g., change default values. The German Institut Wohnen und Umwelt provides a calculation sheet which is flexible and unlocked so that boundary conditions and all input parameters can be adapted to the Austrian norms.

4.3.3.4 Energy Demand for Technical Building Systems

The calculation of the energy demand for technical building systems in residential buildings is restricted to space heating and domestic hot water systems. The basic input parameters in the calculation are, on the one hand, the demand of thermal energy to maintain a set indoor temperature and to heat a fixed amount of hot water to a set water temperature. The heating demand Q_H is a calculated parameter, while the demand for domestic hot water Q_{HW} is defined in ÖNORM B 8110-5. On the other hand, the system energy requirements (losses and auxiliary heat) and system efficiencies of the space heating and domestic hot water systems must be known.

The Austrian Institut für Bautechnik (2007a) defines 8 default systems and specifies for each system the necessary system details for the calculation of the energy demand (see Annex I): standard boiler, low temperature boiler, condensing boiler, combined heating and hot water by gas central heating, district heating, single oven, solar thermal system, and heat pump. The calculation is based on the separate analysis of the subsystems "emission", "distribution", "storage", and "generation" and can be conveniently executed by means of the calculation sheets provided by the OIB.

Institut Wohnen und Umwelt (2005) has also developed a simplified method for a rough assessment of the energy demand for heating and domestic hot water systems based on the correlation between the size of the floor space, the number of full storeys and/or residential units, and different system parameters. It is based on a number of assumptions made concerning system specifications, efficiencies, and building period categories. The corresponding questionnaire requires rather specific information on system-specific parameters, such as the year of installation or manufacture, the type of fuel, the operating conditions, and the insulation standards for different sub-systems. Typical energy demand values and tabulated efficiencies for the calculation of heat loss, recoverable heat, and auxiliary heat for each subsystem are referred to and chosen according to the discrete parameters "number of full storeys" and "number of residential units". Both parameters were grouped into 3 classes.

Pipe length and pipe diameters are necessary input parameters for determining the thermal energy required for heat or hot water distribution, in particular, the linear thermal transmittance of the pipes and losses at the connections. For estimating the dimensions of the pipes, ÖNORM and Institut Wohnen und Umwelt propose two different estimation methods.
Both approaches distinguish between the pipe length from the generator to the shafts, pipe length of the vertical shafts, and of the connecting pipes for the heating system and pipe length of the distribution pipes, ascending pipes, circulation pipe, and stub pipe for the hot water system.
Typical pipe lengths are either determined based on the gross or net floor space, an approach chosen by the ÖNORM, or based on the characteristic length of the building, the number of storeys and the height of the storeys, proposed by the Institut Wohnen und Umwelt. The second method is more accurate, however, it requires that the length and width of the ground plan are known. Furthermore, determining the characteristic length of a building is rather difficult for a ground plan other than a simple rectangle. The ÖNORM estimation method is therefore more practicable for my purpose.

The Adress-GWR database stores data on heating and hot water systems. A second source of information is the building census 2001. Data come in aggregated form, in absolute numbers and percent, and are more generalised than the data in the Adress-GWR whose data structure is modelled on the energy performance certificate and matches the default systems defined by the OIB. The database includes information on the type of heating (central or decentral heating), the heating system, operation mode, type of fuel and heat emission system as well as type of hot water system and system for hot water generation allowing for a calculation according to the simplified ÖNORM procedure.
The data required for the method developed by the Institut Wohnen und Umwelt are mostly represented in the database. However, among the choices in the questionnaire are also systems which are not represented in the database or detailed information is asked (e.g., differentiations must be made between heat pumps with and without heating coil, heat pumps in combination with a boiler and the single heating element).

A comparison of the two methods leads to the conclusion that both apply a high level of generalisation. The OIB proposes 8 default systems and makes assumptions on typical system specifications, while the calculation follows the conventional path. The only necessary information that must be known is, on the one hand, the type of heat supply. Unless more specific information is available, a central system supplying all rooms can be assumed for residential buildings. On the other hand, the type of heating or hot water system is the vital bit of information, which can be obtained from the database.

The Institut Wohnen und Umwelt departs from formulas and system-characteristic values defined in the DIN standards and derived from scientific studies and calculates heat losses, recoverable heat, and auxiliary energy demand for each subsystem for varying assumptions. Out of the resulting matrix, few system-specific representative values are chosen and the calculation procedure is largely simplified. Compared to the ÖNORM method this approach requires more detailed information on the systems installed without adding to the accuracy of the result. The conclusion must therefore be that for the calculation of energy demand for technical building systems the ÖNORM approach is the preferred method.

Fig. 9: Calculation tree energy demand for space heating.

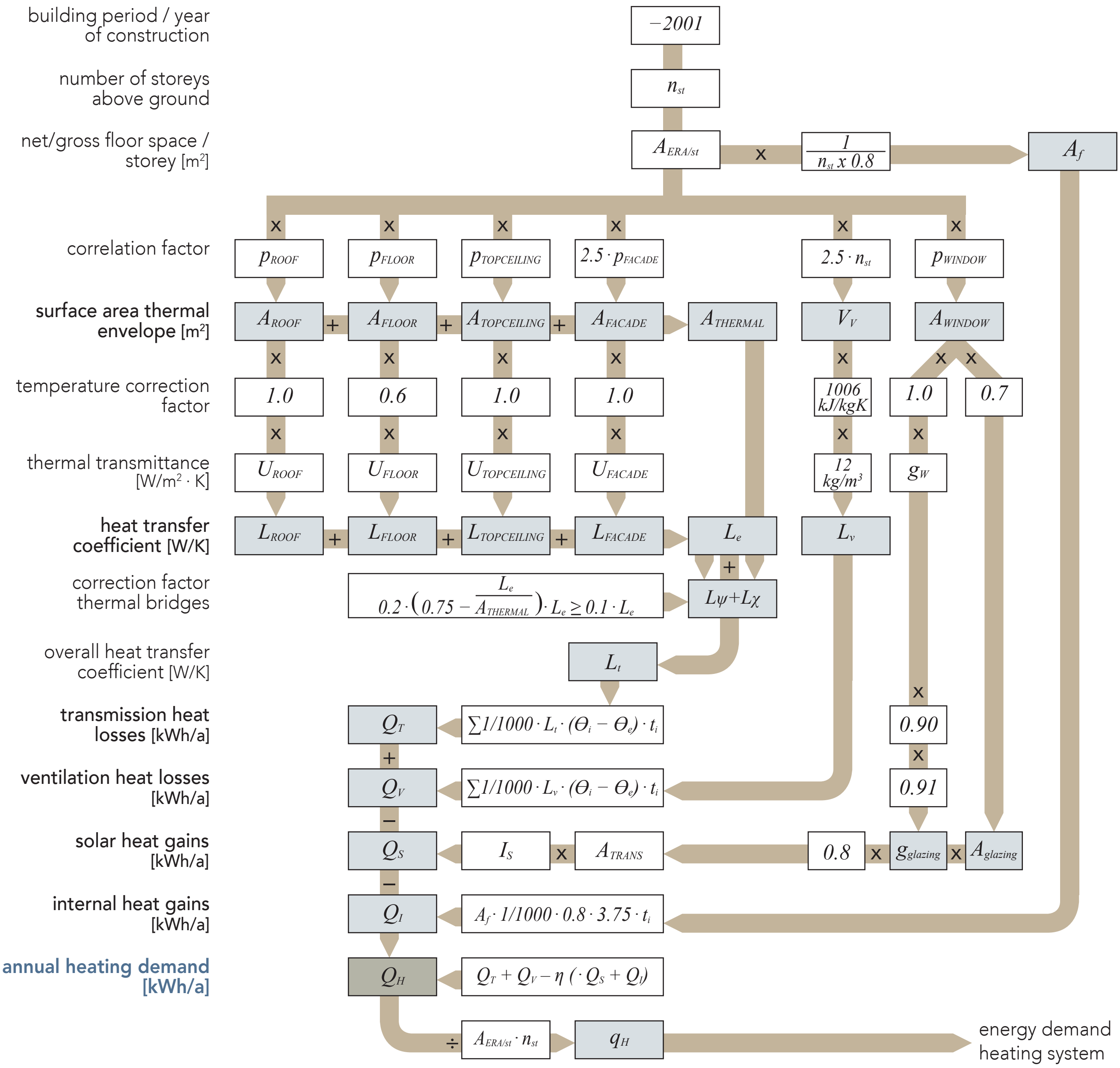
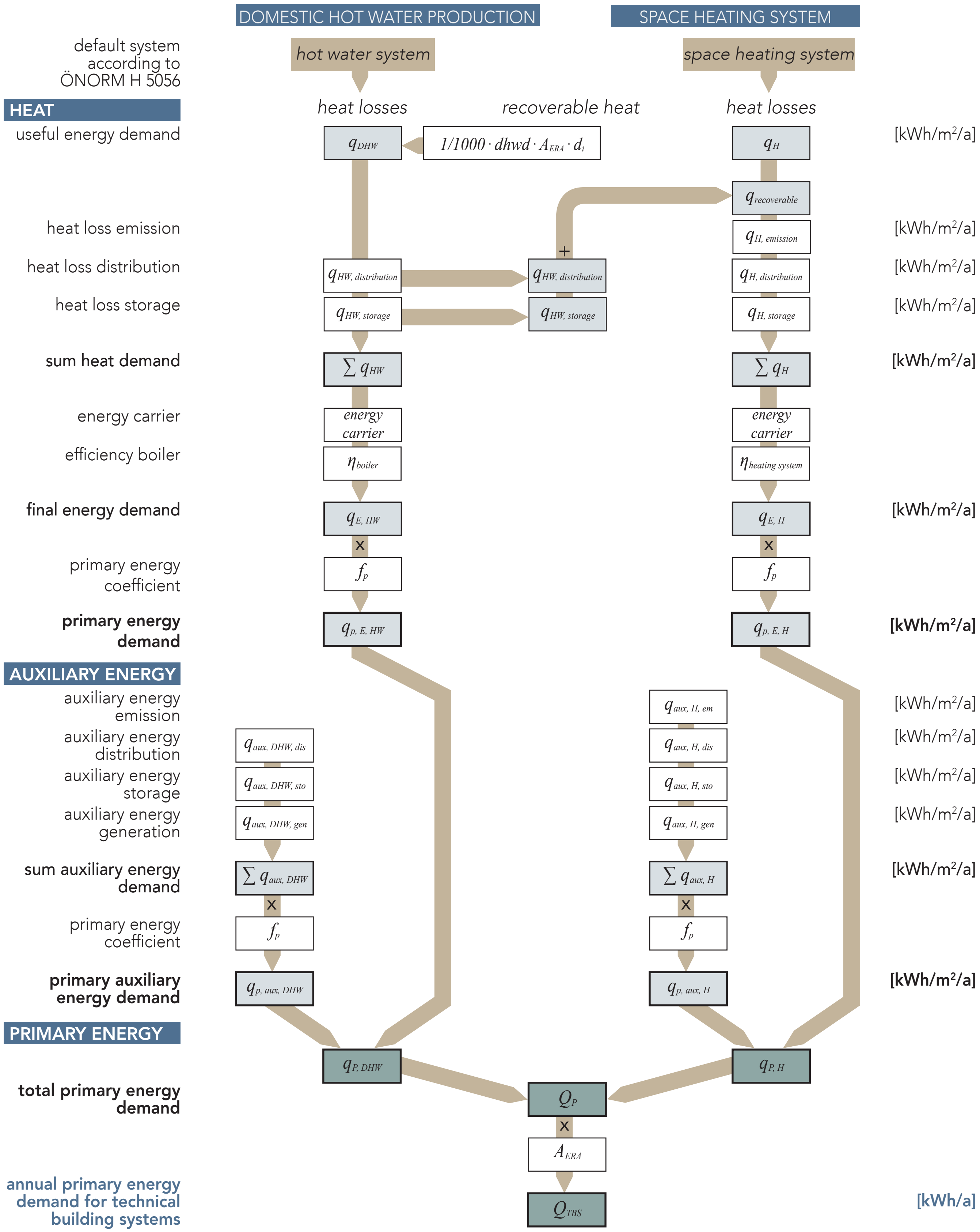


Fig. 10: Calculation tree energy demand for technical building services.



4.3.3.5 Energy Demand for Illumination

Due to its small contribution to the total energy demand for electricity and heat in a residential building, the energy demand for illumination is usually not assessed for residential buildings. The calculation requires mainly knowledge of the annual operating hours, split into daylight time usage and nighttime usage, and specific information on the lighting power installed. The operating hours are defined in the ÖNORM for all types of non-residential buildings, as part of the standardisation of user behaviour. It is easy to see that the operating hours of an office building or school and a residential building are very different. The lighting power depends strongly on the number of light sources and their luminous efficacy. Both pieces of information are not available in the statistics. Given the relatively small share of energy demand for lighting it seems valid to use a more generalising approach. Benchmark values for LENI are defined for the different non-residential building uses and range between ~24 kWh/m²/a for education buildings and ~70 kWh/m²/a for wholesale and retail trade buildings. An approximated value for the demand for lighting could be the mean value of all benchmarks (~40 kWh/m²/a). The annual demand is then calculated as follows:

$$W = LENI \cdot A_{useful} \tag{4.41}$$

$LENI$ … lightning energy numeric indicator [kWh/(m² a)]
W … total annual energy used for lighting [kWh/a]
A_{useful} … total useful floor area of the building [m²]

4.4 Primary Energy Demand Related to the Provision of Technical and Public-Distributive Infrastructure

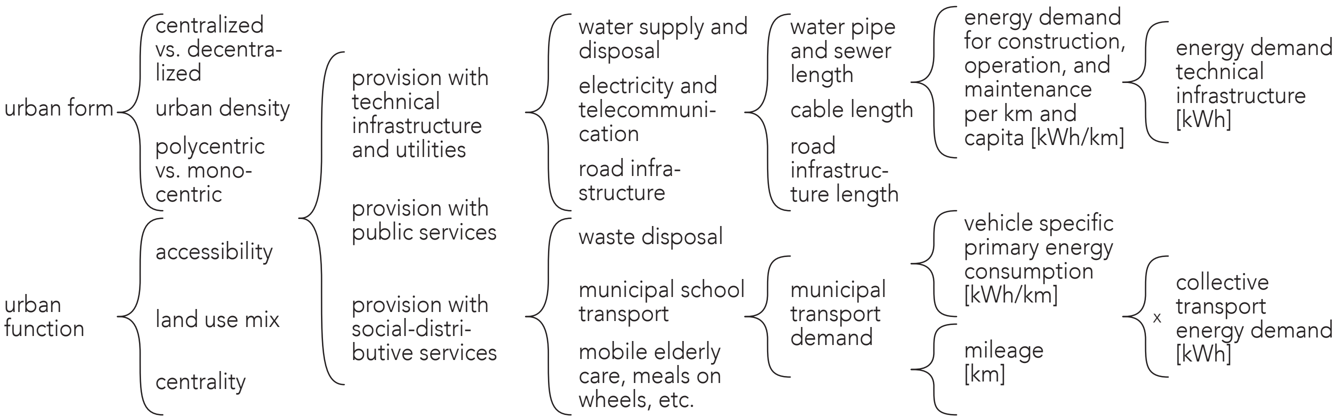
URBAN FORM and development patterns influence public expenditures as the cost per unit of development rises as densities decrease (Doubek & Zanetti, 1999; Doubek & Hiebl, 2001). Large investments are required to extend roadways and other technical facilities that transmit water, sewage, electricity, and other services over longer distances to reach fewer people. The same is true for the provision and operation of public and social-distributive services, such as garbage collection and disposal, municipal school transport, mobile elderly care, meals on wheels, etc.

Providing and running these services and operating and maintaining the necessary infrastructure puts a considerable strain on public budget. This is even more so the case for low density, discontinuous development which undermines the cost-effective provision of urban services. In Austria, the spread of low density scattered settlements incur each year additional costs associated with the construction and maintenance of roads and the water supply and waste water system of estimated 150 Million Euros as compared to denser forms of settlement (Seiß, 2006). Technical and social infrastructure was found to be 3 to 10 times more expensive in suburban areas than in cities.

Only a small fraction of costs is borne by the beneficiaries of the newly built infrastructure[35]. The fact that, generally, public goods and services are priced according to their average as opposed to their marginal cost adds to the problem, as land developers have little motivation to help maintain a cost-effective urban form. As an outcome, growth commonly enjoys significant subsidies as the costs it imposes end up being financed through collective property tax revenues.

But infrastructure demand does not only incur additional costs, but also involves additional energy demand related to the provision of technical and public-social infrastructure. This energy demand, although not showing up directly on a household's energy bill, is, nevertheless, caused by households and must be allocated to them.

Fig. 11: Factors influencing the municipal energy demand for the provision of technical infrastructure and utilities and for the provision of public and social-distributive services.



35 costs borne by the municipality: 16%; cost borne by the fee-payers: 37%; costs borne by the federal government and the federal states: 47%

4.4.1 Assessment Methods for Energy Demand Related to the Provision of Technical Infrastructure

IN AUSTRIA, housing construction and the development of commercial areas and industrial parks are the driving forces behind low-density, spatially expansive development patterns. This development results in considerable costs for the provision of technical infrastructure and facilities which can be characterized by high capital costs and a long life cycle. Furthermore, required quantities (e.g., sewage pipe/meter, roadway/m^2, etc.) depend more on the area that needs to be supplied than on how many residential units the area accommodates thus on the intensity of usage. This means that marginal costs increase as density decreases.

Similarly, the construction and operation of road infrastructure and of supply and disposal systems become more energy-efficient if the demand for infrastructure is to decrease while supplying the same number of residents. However, most studies on the effect of land use planning are concerned with the aspect of macroeconomic costs incurred for the construction and maintenance of road infrastructure and the construction, operation, and maintenance of technical infrastructure while few studies address the contribution of urban density to the energy demand of technical infrastructure.

2-3% of total household energy demand

Ott et al. (2008) find that the energy demand for technical infrastructure and utilities (roads, supply and disposal systems) makes up only 2-3% of total household energy demand. Even though the impact seems rather small it is not negligible in times of tight municipal budgets and debts.

Authors find a strong correlation between infrastructure related energy demand and settlement structure. Results show that less dense settlements have a demand which is ~3,000 MJ/a/cap (~833 kWh/a/cap) higher than that of the densest settlement, taking into account the energy consumption for construction, operation, and disposal of road infrastructure and the supply and disposal facilities (water supply and wastewater discharge, gas, electricity, district heating) from and to properties.

In three out of the four study areas, in those with the lowest floor-space index, construction and disposal consume the bigger part of energy. By contrast, for the urban settlement, which has the highest density, the energy demand for operation is dominant. Altogether, the energy demand during the operating phase does not vary with density, indicating that length and/or area of the infrastructure facilities do not have a significant impact on operating energy demand.

For the following infrastructure facilities energy demand is known to depend on urban structure and density:

- transport infrastructure (roadways, street lighting, pavements)
- water supply system
- waste water system: sewerages, waste water treatment plants, etc.
- electricity and telecommunications supply
- gas supply
- district heat supply

4.4.1.1 Data Sources

Data sources	Data owner	Coverage	Data	Year
Gebäude- und Wohnungsregister; (Gebäude- und Wohnungszählung)	Statistik Austria	Austria; municipality	Features of buildings (optional): Number of households with: - gas connection - sewer connection - water connection	2001
Digitale Katastermappe /Grundstücksdatenbank	Bundesamt für Eich- und Vermessungswesen	Austria; municipality	Total traffic area in municipality; urban density in RU/ha	1995
Road and street map	Navteq	Austria; municipality	Total length of municipal road network	
Population census 2001	Statistik Austria	Austria; municipality	Population of province and municipality	2001
Bundes-Abfallwirtschaftsplan 2011	Bundesminister für Land- und Forstwirtschaft, Umwelt- und Wasserwirtschaft	Austria; province	Per capita household waste production	2009
Kindertagesheimstatistik	Statistik Austria	Austria; municipality (full sample survey)	children looked after in kindergarten (as percent of the total population in municipality)	2009/2010

Tab. 32: Data sources.

Data Sources on Energy Demand

Ott et al. (2008) determine infrastructure related primary energy demand for the total energy embodied in the process from production to disposal. Data for the lifecycle analysis come from a widely used (Swiss) life cycle inventory database[36].

In the assessment, the energy demand embodied in the material, the construction, in transport, and renewal as well as in the disposal of the various infrastructural elements is taken into account. As for the operational phase, the analysis considers only relatively energy-intensive services, such as water supply and waste water discharge, which require energy for the operation of electrically driven pumps and heating in the waste water treatment facilities. To estimate the energy demand of these facilities during operation aggregated Swiss consumption data were used. The authors argue for the use of aggregated vs. actual consumption figures since specific consumption figures in Switzerland are very much shaped by the different requirements defined by the cantons regarding type and number of purification steps. A direct comparison would distort the result in favour of those municipalities with less stringent regulation. Energy demand for the operation of gas and power lines concerning losses within the distribution network of the settlement was neglected as losses are relatively small and below the range of accuracy of the whole assessment and were therefore deemed negligible.

The renewal of streets was considered as part of construction and disposal and the lifetime of the upper road structure was assumed 15 years and 100 years for sewage pipes.

cumulative energy demand

The cumulative energy demand was derived by multiplying the total length of each category of technical infrastructure for the study areas with the specific energy demand for each infrastructure type/element per square metre or running metre.

[36] The ecoinvent database contains 4,000 datasets based on industrial data or data compiled by research institutes and LCA consultants (http://www.ecoinvent.org/database/).

Tab. 33: Cumulative energy demand for different categories of technical infrastructure.

Infrastructure	Cumulative energy demand			
		unit		unit
access road	47	$MJ/(m^2_{road}\cdot a)$	13.1	$kWh/(m^2_{road}\cdot a)$
waste water	88	$MJ/(m_{pipe}\cdot a)$	24.5	$kWh/(m_{pipe}\cdot a)$
water	12	$MJ/(m_{pipe}\cdot a)$	3.3	$kWh/(m_{pipe}\cdot a)$
gas	32	$MJ/(m_{pipe}\cdot a)$	8.9	$kWh/(m_{pipe}\cdot a)$
electricity	7	$MJ/(m_{pipe}\cdot a)$	1.9	$kWh/(m_{pipe}\cdot a)$
district heating	114	$MJ/(m_{pipe}\cdot a)$	31.7	$kWh/(m_{pipe}\cdot a)$

Source: Ott et. al, 2008 and own conversion into kWh

Doubek and Zanetti (1999) stress that costs and energy demand depend not only on required dimensions but also on other parameters, notably of technical nature, such as requirements on volume and capacity, the relief, the subsoil, the distance to the receiving water, etc. Especially for sewer systems and waste water treatment plants, which are rather energy-intense facilities, different technical solutions result in considerable differences in energy demand. Ideally, the sewer system can operate with natural slope, but in flat areas with no or too little slope in the catchment area pumping is needed and usually a pressure and vacuum sewer system is installed. Even though these systems have the advantage of requiring a lower channel depth they are more energy-intensive in their operation.

According to Doubek and Zanetti (1999), for the operation of a separate sewer system around 0.2 – 0.3 kWh are consumed per residential unit and day, while for a combined sewer system, the energy demand is only 0.1 kWh per residential unit and day. Operational energy consumption for aeration and pumping of a waste water treatment plant in 1991 ranged between 35 to 200 kWh per population equivalent, depending on the kind of plant design.

Regarding road infrastructure, energy demand for street cleaning, snow clearance, and gritting services should be inquired separately and included in the cumulative energy demand figure for access road.

Data Sources on Infrastructure Length

To illustrate the relation between settlement type and infrastructure requirements the length or m² per capita is the best suited indicator. However, clearly not all demand for transport and technical infrastructure is caused by households. Industry and trade also require infrastructure areas which, in case a municipality has a significant local industrial zone, may be extensive. By the same token, interstate roads and junctions as well as agricultural and logging roads, etc., cannot, as a matter of logic, be allocated to households. Therefore, and for the purpose of comparison, a decision has to be made regarding which part of the entire municipal infrastructure to exclude from the assessment, as it would otherwise considerably increase the infrastructure demand per capita of a community and distort the result.

In spatial planning terms, a general distinction is made between *Äußere Erschließung* and *Innere Erschließung*.

Äußere Erschließung

Äußere Erschließung includes the superior (federal, regional) road network, such as the connection to main roads, highways, junctions, etc., and infrastructure connecting different communities or different parts of a city or village, such as high voltage transmission lines and lines outside the built-up area. For any particular building site, *Äußere Erschließung* denotes infrastructure necessary to connect the site to existing public transport areas, thus, it includes all traffic and infrastructure facilities outside the building land or lot. The *Äußere Erschließung* is planned on the level of zoning plan (*Flächenwidmungsplanung*) which divides the territory of the municipality into different land use categories, mainly into building land, transportation zones, and green land, (mostly) on a scale 1:5,000. For building land to be declared a building site, the access to existing public transport areas or transport zones as well as access to technical infrastructure must be provided for in the zoning plan. Required dimensions depend primarily on the site of the building land within the municipality and on existing technical infrastructure.

Innere Erschließung

Innere Erschließung includes the connecting infrastructure between houses, such as local (municipal) roads (e.g., residential access roads), and the local supply and disposal systems. In the case of a newly developed building site it describes the technical site development necessary to connect all residential units to the network. Technical site development (*Innere Erschließung*) is planned on the level of building regulation plan (Bebauungsplan) which is drawn up for the entire building land defined in the zoning plan or for parts of it on a scale 1:2,000 and smaller. It includes all technical facilities that are necessary for site utilization within a building zone, such as access roads, water supply and sewerage, etc., required for a proper use of a building plot. Required dimensions depend very much on the type of building, the building (alignment) line, road alignment line and course, width and height of transport zones, and on specifications of the building density stipulated in the building regulation plan. Outside cities little use is made of this planning instrument which is why density specifications are mostly contained in the zoning plan instead of the building regulation plan (Salzburger Institut für Raumordnung & Wohnen, 2007).

Doubek and Zanetti (1999) find that, for all settlement types, the length of the local (distribution) network, including the entire *Innere Erschließung* as well as parts of the *Äußere Erschließung*, commonly makes up 80-90% of the entire municipal network. For roads, this becomes most apparent as federal and regional roads do not only connect different municipalities but often also serve as access roads to residential buildings. For the comparison of different settlement types and densities it is necessary to include these road sections. Another imprecision concerns transport areas on private property which, in this approach, are not considered. Likewise, no distinction is made between buildings aligned to the property's boundary or freestanding buildings, which require additional sewer length to connect the building to the sewer system.

Data on infrastructure lengths for water supply, sewer, and transport infrastructure for different settlement types were empirically determined by Doubek and Zanetti (1999) with the purpose of gaining generalizable and transferable results to project future costs of infrastructure development in Austria. They included 18 settlements in their study for which they determined the *Innere Erschließung* delimited by the most peripheral buildings. Scattered settlements, hamlets and isolated farms are considered as part of the settlement area, however, for a more sound and refined result they distinguish between the main village and other hamlets and scattered settlements pertaining to the municipality. They find a strong correlation between density and infrastructure length and a wide range from 1.5 to 40 running metres per inhabitant and working place for the different communities.

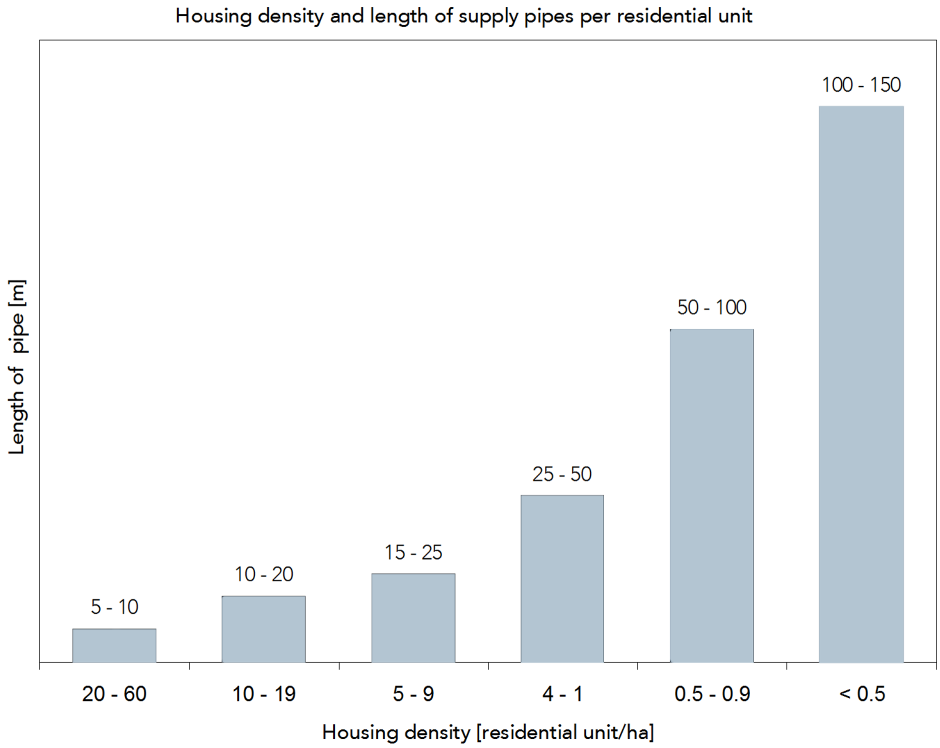


Fig. 9: Relationship between residential density and length of water and waste water supply pipes per residential unit. (Doubek & Zanetti, 1999)

sewer and water supply system

Findings furthermore indicate that actual figures depend very much on local conditions. The authors observe that, in particular for low density settlements, the networks of water pipes, sewers, and streets have very similar lengths provided the community is entirely connected to the public sewer and water supply system. However, at the time when the study was carried out the proportion of the population served by connections to the sewerage system, to a central wastewater treatment facility, and to public water supply was much lower than today, in particular as regard the connection to the sewer system which today is close to 100%. Data on the number of households connected to water supply (sewerage and gas) can be retrieved from the "*Gebäude und Wohnungsregister*" of the statistical office.

A comparison of infrastructure costs for a model settlement with different urban densities carried out by the Salzburger Institut für Raumordnung und Wohnen (2007) comes to a different result. Findings indicate that water pipes are approximately 10% and gas pipes, district heating pipes, and electric cables about 20% longer than sewers. For water supply, pipe lengths further depend on whether the settlement is centrally supplied or decentrally supplied.

sewerage

For sewerage, sewer length per residential unit is very variable even for communities with the same density and dimensions depend very much on the local situation. Doubek and Zanetti (1999) found that within a density class sewer length per resident may be shorter for linear settlements, while for settlements in steep terrain it might be twice as long.

transport infrastructure

Regarding transport infrastructure, energy demand per resident depend very much on the degree of asphalted streets which in very scattered settlements was found to be only 50 to 60% of the total road network. For the study of Doubek and Zanetti, the length of the total municipal road network was either inquired or estimated due to the lack of statistical data on the extension of municipal roads. If more reliable values are needed, one should refer to GIS-data. After all, for the calculation of energy demand, not so much the length, but the area is important. Therefore, data from maps are in either case the better choice.

Since lengths of infrastructure per residential unit are given as range, the actual values can be approximated with the following formula:

$$L_{infra} = lr_{pipe} + \frac{(ur_{pipe} - lr_{pipe})}{(ur_{density} - lr_{density})} \cdot (x_{density} - lr_{density}) \qquad (4.42)$$

L_{infra} … length of infrastructure per residential unit [rm/RU]
lr_{pipe} … lower range value of piping or cable length [rm/RU]
ur_{pipe} … upper range value of piping or cable length [rm/RU]
$lr_{density}$ … lower range urban density [RU/ha]
$ur_{density}$ … upper range urban density [RU/ha]
$x_{density}$ … actual value urban density [RU/ha]

Settlement class:				
Description	Class	Road and sewer length per RU	Water pipe length per RU	Gas and district heating pipe and electric cable length per RU
urban settlement	> 60 residential units/ha	1 – 5 m	1.1 – 5.5 m	1.2 – 6 m
high density settlement	20 – 60 residential units/ha	5 – 10 m	5.5 – 11 m	6 – 12 m
compact settlement	10 – 19 residential units/ha	10 – 20 m	11 – 22 m	12 – 24 m
sprawling settlement in peri-urban area	5 – 9 residential units/ha	15 – 25 m	16.5 – 27.5 m	18 – 30 m
low density settlement	1 – 4 residential units/ha	25 – 50 m	27.5 – 55 m	30 – 60 m
scattered settlements with dynamic growth	0,5 – 0,9 residential units/ha	50 – 100 m	55 – 110 m	60 – 120 m
very scattered (traditionally agrarian) settlements	< 0,4 residential units/ha	> 100 m	> 110 m	> 120 m

Source: Classification according to Doubek & Zanetti, 1999; values adopted according to Salzburger Institut für Raumordnung & Wohnen, 2007.

Tab. 34: Relation settlement class and infrastructure length.

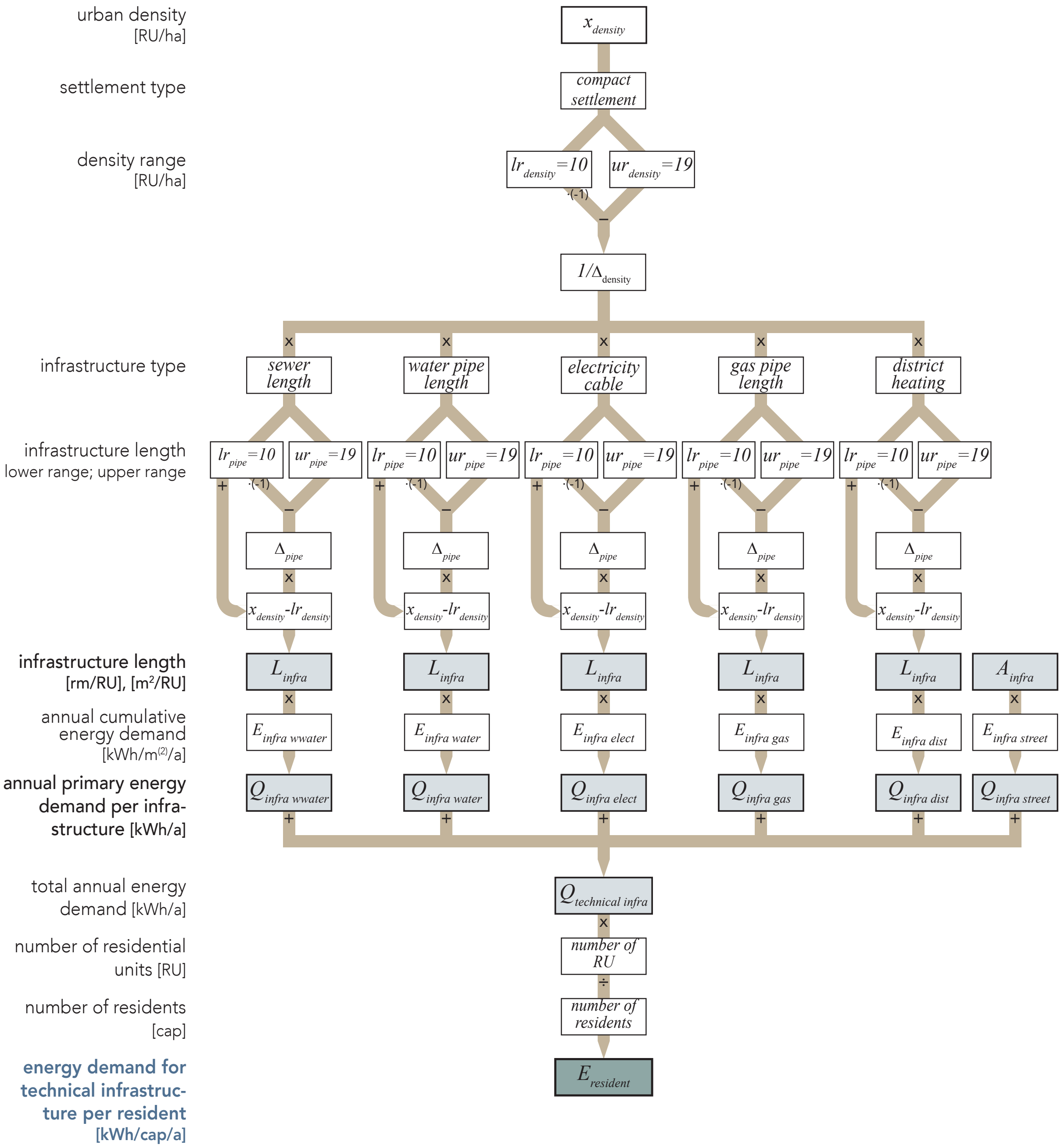
4.4.2 Calculating the Primary Energy Demand for Technical Infrastructure

The specific energy demand per capita for technical infrastructure is calculated as follows:

$$E_{resident} = \sum E_{infra} \cdot L_{infra} \cdot \frac{RU_{community}}{n°residents_{community}} \tag{4.43}$$

$E_{resident}$ … annual cumulative energy demand for techn. infrastr. per resident [kWh/cap/a]
E_{infra} … annual cumulative energy demand for technical infrastructure per square metre or running metre infrastructure type [kWh/m(2)/a]
L_{infra} … length or area of infrastructure type per residential unit [rm/RU]
$RU_{community}$ … number of residential units in the community [RU]
$n°residents_{community}$ … number of residents in the community [cap]

Fig. 13: Calculation tree energy demand for technical infrastructure.



4.4.3 Assessment Methods for Energy Demand Related to the Provision of Public Services and Social Infrastructure

LOCAL PUBLIC SUPPLY structures, or the lack of local provision with important basic social services, may generate traffic or divert motorized traffic from non-motorized traffic, such as walking or biking. This includes, for instance, schooling and child care, care for the elderly and health services, social housing, waste disposal, municipal public transportation, the provision of cultural, sports, and other leisure facilities, etc. The larger the share of population that can reach these central infrastructures within acceptable walking distance, commonly assumed to be 5-15 minutes, the more likely these trips will be made on foot.

Furthermore, municipalities may need to organise collective transportation for less mobile parts of the population, such as children, elderly people, or the disable, if key public infrastructure are not reasonably close, causing additional public expenditures and energy demand for mobility.

Another aspect of energy consumption related to public services is in the area of municipal services including municipal waste management, street cleaning and snow clearance. The larger the distances that have to be covered to serve a relatively smaller number of people the more energy-consuming these services become per inhabitant.

Thus public (social) infrastructure covers a broad spectrum. However, only those services that have an energy demand which is linked to spatial structure and that are assumed to be offered by most communities are considered in this paper:

- mobile nursing services and "meals on wheels",
- collective transportation of pre-school and school children,
- waste disposal, garbage collection,
- street cleaning, snow clearance and gritting services (as part of the demand of technical infrastructure).

Public transportation is also a public service, but will be considered as part of the energy demand for mobility.

4.4.3.1 Data Sources Social-Distributive Services

Following the study on the costs of technical infrastructure (Doubek & Zanetti, 1999), Doubek and Hiebel (2001) investigate the relationship between costs of social infrastructure and different forms of settlement characterized by different densities and population dynamics. 22 small and middle-sized municipalities (<15,000 inhabitants) were selected and analysed regarding their offer of community-based social infrastructure and related costs. Based on the results of both studies a general correlation between density and other morphological parameters and transport distance was formulated in order to get generalizable and transferable results that can be applied to other municipalities. While transport distances and, hence, costs were generally found to increase with decreasing density, findings also showed that transport distances depend on a combination of factors rather than on density alone. First of all, the demographic profile of a community plays an important role. Dynamically growing communities have a larger share of children of kindergarten or school age that may need collective transportation. On the other hand, in structurally weak regions an aging population is likely to increase the need for elderly care. As for morphological parameters other than density, linear settlements that have developed along a main road often show shorter transport distances as compared to more radiocentrically developed communities. Furthermore, linear settlements can often do without separate transportation as existing public transportation along the main access road can fulfil this municipal task. The parameters derived from empirically determined values based on a small set of case studies are therefore only useful for comparing different settlement structures but may poorly represent the actual situation and transport requirements of a particular municipality.

collective transport of pre-school and school children

The need for collective transportation of pre-school and school children is influenced by density and by morphological parameters with regard to the number of children that need transportation and the distances to and from school or kindergarten. Compact settlements generally do not need to provide transportation and the same is true for less dense settlements with more than one kindergarten as long as they are conveniently located as to be reachable within walking distance for the most part of the population. On the other hand, for compact but large settlements with only one kindergarten and school location, transportation may be nevertheless required if distances get too long. For low density settlements daily distances per child were found to be around 1.7 to 3.6 km. Scattered settlements almost always need to provide collective transportation with distances ranging between 3 to 4 km per child and day. A reduction of transport distances can be achieved if children are picked up at several pick up places instead of being transported from door to door. It is important to note that transport distance values are expressed as figures relative to the totality of (pre-) school children. Therefore, the actual distances might be considerably longer if only a small number of children in a community is brought to school by (pre-) school transport.

mobile elderly care and meals-on-wheels

Nursing and elderly care including home care or home assistance services and "meals on wheels" are not offered in every municipality and few communities provide both services. Distances for mobile nursing services and meals on wheels also tend to increase with decreasing density; however, correlation is less strong and due to the small number of people using these services transport distances are strongly influenced by the spatial distribution of clients. Furthermore, the relationship between transport distance and urban structure is only applicable if services are provided centrally from one location within the municipality. This assumption is not always correct, for some municipalities are served by institutions which are organised on a district or regional level or are served by a neighbouring municipality. Transport distances for compact settlements were found to range from 700 m to 2.7 km. Sprawling settlements in suburban and peri-urban areas had distances between 800 m to 1.9 km for every meal delivery and between 3 and 5.6 km per client for mobile nursing services. In scattered settlements, transport distances were found to be between 3 and 6 km, with the values referring to the actual number of clients.

The authors express the relationship between urban density and transport distances as an ideal typical function under the assumption that the services are provided from one location in the municipality. The transport distance per client is then the result of total road length divided by the number inhabitants in percent that make use of the service.

This was found to be between 1 and 2% of the population for mobile nursing services and "meals on wheels" and between 2 and 4% for (pre-) school transport. For school transport, the ideal typical curve is expressed as the share of children looked after in kindergarten as percent of the total population. Recent values for each municipality can be retrieved from annual publications of the statistical office (Statistik Austria, 2011).

Tab. 35 presents typical density-dependent transport distances for social-distributive services. Tabulated data are taken from the graph in Annex I (Fig. 19) and are therefore subject to inaccuracies.

Tab. 35: Transport distances depending on urban density.

Settlement class: Description	Class	Collective (pre-) school transport				Mobile nursing services and "meals on wheels"			
		1%	2%	4%	6%	0.5%	1%	2%	3%
urban settlement	> 60 residential units/ha	0 – 200m	0 – 80m			0 – 200m	0 – 80m		
high density settlement	20 – 60 residential units/ha	201 – 450m	81 – 250m	0 – 80m		201 – 450m	81 – 250m	0 – 80m	
compact settlement	10 – 19 residential units/ha	451 – 1000m	251 – 600 m	81 – 220m	0 – 150m	451 – 1000m	251 – 600 m	81 – 220m	0 – 150m
sprawling settlement in peri-urban area	5 – 9 residential units/ha	1001 – 2000m	601 – 1150m	221 – 550m	151 – 320m	1001 – 2000m	601 – 1150m	221 – 550m	151 – 320m
low density settlement	1 – 4 residential units/ha	2001 – 4100m	1151 – 2100m	551 – 1050m	326 – 700m	2001 – 4100m	1151 – 2100m	551 – 1050m	326 – 700m
scattered settlements with dynamic growth	0,5 – 0,9 residential units/ha	> 4100m	2101 – 3900m	1051 – 2050m	701 – 1400m	> 4100m	2101 – 3900m	1051 – 2050m	701 – 1400m
very scattered (traditionally agrarian) settlements	< 0,4 residential units/ha		> 4000m	2051 – 4500m	1401 – 2750m		> 4000m	2051 – 4500m	1401 – 2750m

Source: Doubek & Hiebl, 2001

4.4.4 Calculating the Primary Energy Demand for Social-Distributive Services

SINCE THE TYPICAL transport distance for collective school transport and elderly care is given as range, $L_{transport}$ can be determined analogous to L_{infra} according to formula 4.42. The specific energy demand per capita for technical infrastructure is calculated as follows:

$$E_{resident} = \left(\sum E_{transport} \cdot \frac{L_{transport}}{1000} \cdot \frac{x}{100} \cdot n°journeys \cdot RU_{community} \right) \Big/ n°residents_{community} \qquad (4.44)$$

$E_{resident}$ … annual primary energy demand for social-distributive infrastructure per resident [kWh/cap/a]
$E_{transport}$ … specific primary energy demand per km and means of transport [kWh/km]
$L_{transport}$ … typical transport distance per residential unit according to the percent of the population that makes use of the service [m/RU]
x … percent of the population that makes use of the service [%]
$n°journeys$ … number of annual transport journeys
$RU_{community}$ … number of residential units in the community [RU]
$n°residents_{community}$ … number of residents in the community [cap]

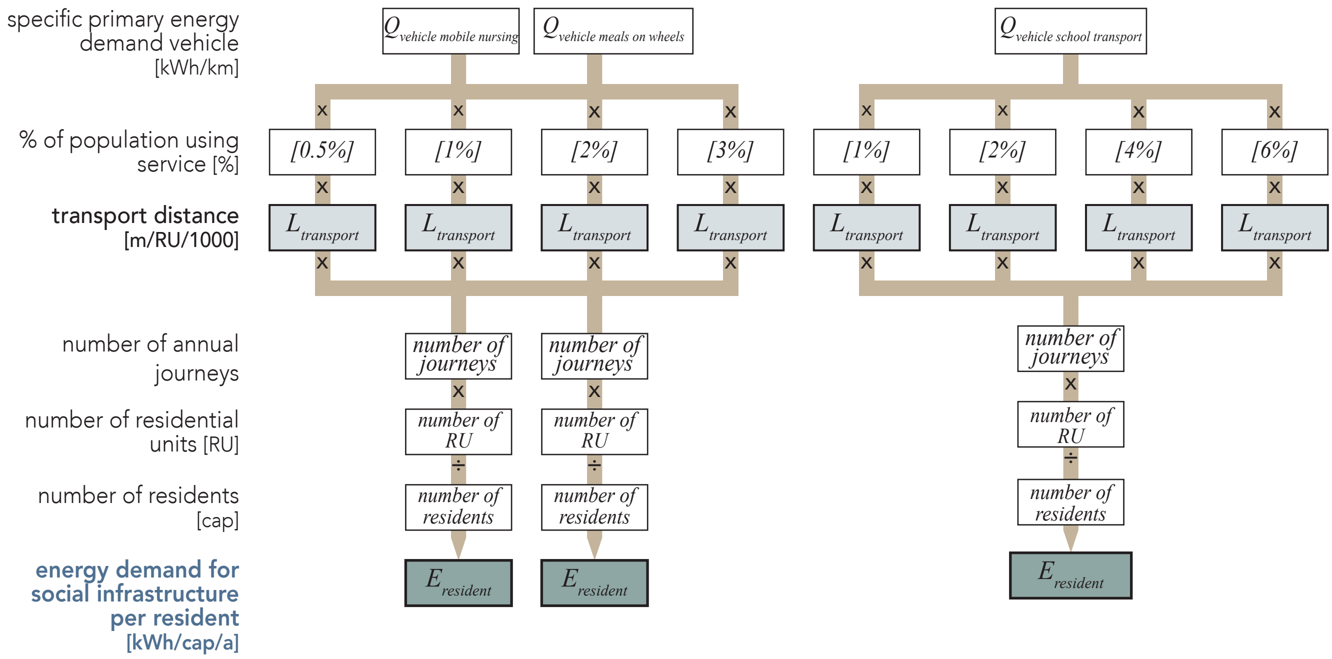


Fig. 14: Calculation tree social-distributive services.

4.4.4.1 Data Sources Waste Collection

garbage collection

For the assessment of the energy demand for garbage collection no comparable study exists to the author's knowledge. The most straight forward approach to assessing energy demand for garbage collection would be to enquire annual fuel consumption data for the municipal garbage trucks, provided this data is collected. However, problems arise when these energy consumption data are used for comparison because waste collection may be organised very differently in each municipality. This is due to the fact that legislation in the area of waste management is split between EC legislation, federal legislation (in part transposed EU legislation) and provincial legislation. Furthermore, municipalities have considerable discretion regarding law enforcement. This concerns notably the organisation of waste collection with respect to how often collections take place, size and type of containers to be used, the positioning of the containers for collection (mostly kerbside collections), as well as the setting of waste collection fees. In addition, municipalities have the possibility to organise garbage collection themselves, together with another municipality, or to form waste associations where various communities are serviced by a service company.

The decision, which types of wastes are collected from each household and which types of waste have to be disposed of in containers put up at local collection points is left to the communities.

household waste

Household waste (residual waste) is in any case collected door-to-door by municipal waste collection trucks, but the frequency of collection varies strongly from once per week (mainly in towns and large communities), to every other week, to once per month.

biodegradable waste

Biodegradable waste is also collected from the households on a regular basis (weekly or every 14 days) by most, yet not all municipalities. Besides, in rural areas, where houses have a garden, organic waste is mostly composted individually.

waste paper and plastic

As for paper and plastic, they are sometimes collected (e.g., once per month), but most communities have containers at local collection points where residents are required to take their waste. But, again, this is something that is decided autonomously by the municipality.

In addition, municipalities have the possibility to exclude properties from collection in case the collection is not economically justifiable due to the difficult accessibility of the property or its distance from other urbanized areas.

Transport Distance

Comparison of energy demand related to waste collection is therefore difficult, not only because conditions are so very different. It is also highly variable because energy consumption depends not only on transport distances per household or resident (attributable to settlement structure and urban density) but also on a number of other factors:

- the specific energy consumption of the waste collection vehicles;
- the topography of the municipality as a hillside location increases fuel demand;
- the load capacity of the vehicle and the amount of waste produced per capita which determine the maximum length of a route;
- the frequency of waste collection and the number of wastes that are collected separately;
- the planning of the routing (which is also connected to the load capacity of a vehicle).

There are basically three ways of getting data on annual transport distances of waste collection vehicles in a municipality:

Annual mileage of the garbage trucks as well as the appointed days for each collection and the types of waste that are collected can be simply enquired at the municipality or from the service company that carries out the waste collection on behalf of the municipality. This approach requires, however, that such information is available and is readily passed on. Furthermore, it has to be "normalized" for the frequency of collection to allow for comparison. Route lengths can also be retrieved from GIS data by measuring the total length of municipal road network or by using the same data on road length/residential unit as in Fig. 10 for the estimation of transport distances per residential unit. A third option would be to use a standard GIS-based vehicle routing software to determine (the optimal) route/s and multiply it/them by the number of collections per year (cf. Schedlberger, 2011).

dependency specific fuel consumption, load, and transport distance

Since there is a dependency between specific fuel consumption, load, and transport distance, which can be expressed by formula 4.45, it can be used to determine the number of collections necessary (Krismer, 2003). Provided that the amount of waste produced in a municipality per year and the average vehicle load are known the number of collections can be easily calculated. Once the truck is fully loaded the waste is either transported directly to the nearest treatment facility or brought to a transfer station where it is containerised and loaded up into a larger vehicle (container truck or freight train) and sent from there either to a landfill or to an alternative waste treatment facility. Since the distance from the community to the nearest facility where the waste is treated, disposed, or landfilled depends very much on the location and number of treatment plants in a re-

Tab. 36: Residual waste from municipal waste collection 2009. In 2009, around 1,402,100 tons of residual or municipal solid waste were collected from households or other sites of waste generation, such as industry or public administration, from kindergartens and schools, hospitals, small businesses, agriculture, etc., served by municipal waste collection. By residual waste, all types of solid waste, excluding separately collected wastes such as recyclables, hazardous substance, compostable organic waste, construction, and demolition waste, etc., are meant.

gion and not on the settlement structure, it will not be considered. However, to account for deadhead trips and additional mileage (e.g., from the garage to the start point of the route, to the transfer station, driving in and back out of a street, etc.) the total transport length will be multiplied by 1.5 assuming the transfer station to be a single location within the municipality.

Residual waste from municipal waste collection 2009 (figures are rounded)			
Province ("Bundesland")	in tons/a	in kg/inhabitant/a	inhabitant in 2009
Burgenland	28,800	102	283,118.00
Carinthia	97,500	174	560,605.00
Lower Austria	218,300	136	1,605,122.00
Upper Austria	170,400	121	1,410,403.00
Salzburg	92,000	174	529,217.00
Styria	151,200	125	1,207,479.00
Tyrol	96,400	137	704,472.00
Vorarlberg	31,600	86	367,573.00
Vienna	515,900	306	1,687,271.00
Austria	1,402,100	168	8,355,260.00

Source: (Krismer, 2003; Statistik Austria, 2009b; Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2011)

Energy Consumption per Transport Vehicle

There are different waste collection vehicles in use that have different technical specifications and load capacities and, hence, different fuel consumption per tonne-kilometre (tkm).

2-ax rear loader

The 2-ax rear loader (*2-Achs-Pressfahrzeug*) is a vehicle that is mainly in use in urban neighbourhoods where increased manoeuvrability is required due to narrower streets and driveways. Owing to its smaller size, the relation between net weight and full load weight deteriorates. This causes higher transport costs and increases energy consumption.

Tab. 37: Technical specifications 2-ax rear loader.

Technical specifications 2-ax rear loader	
net vehicle weight	11.00 t
maximum permissible gross vehicle weight	18.00 t
maximum vehicle load capacity	7.00 t
average payload with household waste	4.190 t

Source: Krismer, 2003

3-ax rear loader

The 3-ax rear loader is a vehicle that is equipped with a third axis and, therefore, has a higher permissible gross vehicle weight. As the increase in size does not increase the net weight as much as it increases the permissible gross vehicle weight the energy and cost efficiency of the vehicle improves. For this reason, 3-ax vehicles are preferred over 2-ax vehicles wherever their use is possible. Newer vehicles now have 4 axes and achieve an even higher efficiency, but are not that widely used.

Tab. 38: Technical specifications 3-ax rear loader.

Technical specifications 3-ax rear loader	
net vehicle weight	12.90 t
maximum permissible gross vehicle weight	26.00 t
maximum vehicle load capacity	13.10 t
average payload with household waste	10.145 t
Source: Krismer, 2003	

4.4.5 Calculating the Primary Energy Demand for Waste Collection

WITH THE FOLLOWING simplified formula, assuming a linear increase in consumption, the energy consumption per kilometre can be calculated with regard to the actual load (capacity) (Krismer, 2003):

$$E_{truck} = \frac{\left(m_{load} \cdot \left(\frac{F_{full} - F_{empty}}{m_{full}} \right) + F_{empty} \right) Hu \cdot \rho_{diesel}}{m_{load}} \quad (4.45)$$

E_{truck} … specific primary energy demand of garbage truck per tonkilometre [kWh/tkm]
m_{load} … weight of load [t]
m_{full} … maximum weight of load [t]
F_{full} … fuel consumption fully loaded [l/km]
F_{empty} … fuel consumption empty [l/km]
Hu … lower heating value of diesel [11.69 kWh/kg]
ρ_{diesel} … density of diesel [0.83 kg/l]

Tab. 39: Conversion factors fuel consumption for garbage trucks. *average payload of 2-ax rear loader: 4.190 t; **average load of 3-ax rear loader: 10.145t

Conversion factors fuel consumption for garbage trucks to kWh			
Truck type: rear loader, "Rotopress"	final energy consumption [l/100km]	primary energy consumption [l/km]	primary energy consumption [kWh/km]
2-axel vehicle			
consumption (empty)	24	0.26	2.56
consumption (full load)	30	0.32	3.20
consumption (average load*)			0.685 kWh/km/t
3-axel vehicle			
consumption (empty)	28	0.30	2.99
consumption (full load)	38	0.40	4.06
consumption (average load**)			0.361 kWh/km/t
Source: Krismer, 2003 and own calculation			

By determining the energy consumption (in kWh) per kilometre and ton and multiplying it by the annual production of waste in the municipality and by the annual mileage of the garbage truck divided by the number of residents in the community we get the energy consumption which can allocated to one resident.

The entire route extends over a distance that is longer than the length of the entire municipal road network since several distances have to be covered more than once (e.g., the way from the garage to the beginning of the route, the way from the ending of the route to the transfer station, driving in and backing out of a street, etc.). To account for this additional mileage, the total route length will be multiplied by 1.5.
To determine the total number of collections of household waste a collection frequency of every two weeks (26 collections per year) will be assumed; other types of collections will not be considered.

$$E_{resident} = \frac{E_{truck} \cdot waste_{province} \cdot n°residents_{community} \cdot transport\ distance_{community} \cdot 1.5 \cdot 26}{n°residents_{community}} \quad (4.46)$$

$E_{resident}$ … primary energy demand for waste collection per resident [kWh/t/km]
$waste_{province}$ … waste produced per capita and year in a "Bundesland" [t/cap/a]
$n°residents_{community}$ … number of residents in the community [cap]
$transport\ distance_{community}$ … total extension of the route [km]

specific primary energy demand garbage truck per ton-km [kWh/km]

waste produced per capita & year [t/cap/a]

total extension of the route [km]

correction factor

number of annual collections

energy demand for waste collection per resident [kWh/cap/a]

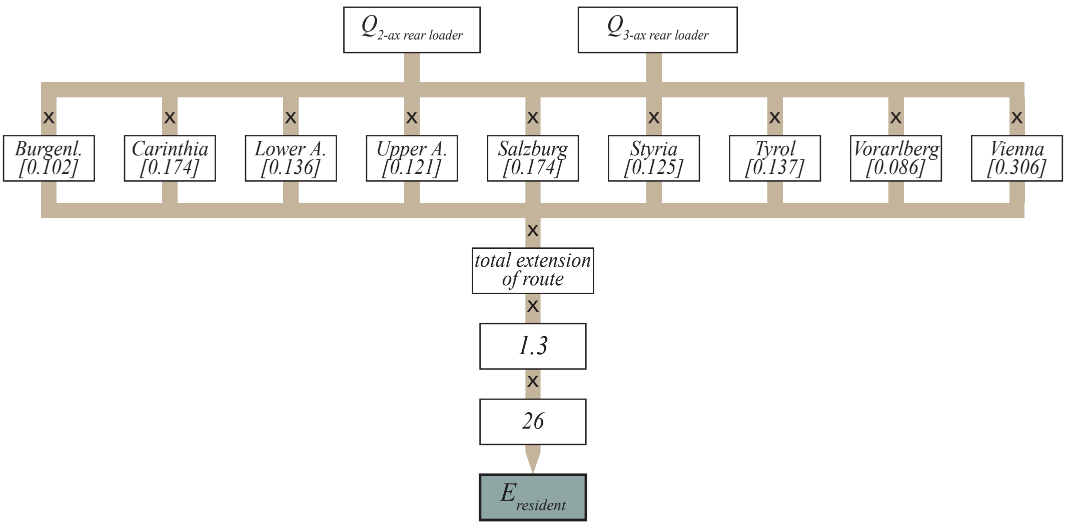


Fig. 15: Calculation tree energy demand for waste collection.

4.5 Primary Energy Demand Related to Mobility

TRANSPORTATION AND URBANIZATION are closely linked. The growth of cities to today's extents and relatively modern phenomena such as urban sprawl were only possible due to the rapid spread and use of the automobile. Several negative side-effects are associated with the increased use of private vehicles such as land consumption, air pollution, noise, but also energy consumption and the release of CO_2 to the atmosphere. According to Hickman and Banister (2005) there are at least three ways that spatial planning can positively influence the reduction of private motorized transport:

- land use mix by locating a mix of uses in close vicinity to each other and thereby making multiple trip chaining possible;
- spatial density by reducing journey distances;
- modal split by encouraging a shift to public transport, cycling, and walking.

4.5.1 Literature Review

WHILE FEW PUBLICATIONS deal with all implications of land use and urban form on energy consumption, publications on the potential contribution of land use planning on the increase in car-based travel received large coverage in scientific literature. A considerable stock of peer-reviewed literature on urban density and transportation has accumulated over time and a large part of it dates back to the 1970s and 1980s. The topic had received a great deal of attention at that time, because high fuel prices caused by the oil crisis raised concerns about energy security and, consequently, about the unsustainability of urban sprawl and suburbanisation.

The first and most ground-breaking studies in this field were those of Newman and Kenworthy (P. W. G. Newman & J. R. Kenworthy, 1988; Peter W. G Newman & Jeffrey R Kenworthy, 1989). In their first study, the authors collect cross-sectional data on land use, automobile use, transit, and other transportation factors like parking facilities and road length for 32 cities in Europe, North America, Asia, and Australia and calculate correlations between fuel consumption and density variables. They adjust for differences in gasoline price, income, and vehicle fuel efficiency using short-term and long-term elasticities and report a strong negative correlation between fuel consumption per capita and urban density. The study has been criticised on several grounds: a fundamental problem is that of comparing places with very different cultural, political, and historical contexts. Furthermore, the study provides only a very general understanding of the relationship between urban form and travel. The use of average density for a city masks variations of density within the city and the use of per-capita gasoline consumption as measure of travel masks differences between cities with respect to travel for different purposes.

Moreover, the first studies by Newman and Kenworthy have been criticised for investigating car-dependency by using data on gasoline consumption instead of data on actual car use. Therefore, they extended their analysis to such factors as income, gasoline price, and car ownership and found that median family income in the case study cities shows no correlation whatsoever with gasoline consumption, though consumption is significantly related to gasoline price. Findings also show that, in the ten case study US cities, vehicle ownership is significantly correlated with urban structure parameters, but not so with income. They also determine for their sample that the size of a city does not correlate with gasoline consumption. Indeed, they find that smaller cities appear to have higher, not lower, automobile travel, which is the reverse of what one would expect and conclude that size is less important than other physical planning parameters.

Addressing theses criticisms studies gradually grew in complexity by adding new variables as well as extending the number of samples. In Kenworthy (2008) the author provides a review of private and public transport, urban form, energy use, modal energy efficiency, and CO_2 emissions patterns in an international sample of 84 cities in the USA, Canada, Australia, Western Europe, high and low income Asia, Eastern Europe, the Middle East, Africa, Latin America, and China. Factors included were urban density, transport infrastructure, car ownership and use, public transport, and non-motorized mode use. The study finds, inter alia, that average per capita energy use in private passenger transport is about 24 times higher in the study's US cities, with the US being the world's heaviest passenger transport energy user and CO_2 producer, than in the Chinese cities. On the other hand, Eastern European cities experience the highest contribution from public transport (31%). Furthermore, the author concludes from the sample that wealth is not a fundamental explanatory variable in understanding car use and energy use patterns in urban transport systems. Physical planning and infrastructure differences were found to be more important.

4.5.1.1 Research Gaps

In researching the relationship between urban density and mobility behaviour a number of areas has been extensively dealt with such as "the influence of population size, density, the provision and mix of local facilities, local urban form, the location of development, balance of jobs and housing and also wider socio-economic variable, for example, the influence of income and household composition (Hickman & David Banister, 2005)."

However, according to Hickman and Banister (2005) research gaps and uncertainty still exist regarding the impact of

- resident population size and resident population density and the optimum urban form in reducing car travel (ranging from compact cities to "decentralised concentration" and even low density suburban spread),
- the local provision and mix of services and the local provision of facilities,
- the distance from the urban centre, and
- socio-economic factors

on travel distance, modal choice, and energy consumption.

Most studies could demonstrate a strong negative correlation between urban density and fuel demand, which is intuitively logic: in denser cities travel distances are often shorter, the share of walking and cycling trips tends to be larger, and a compact public transport network becomes more viable allowing for alternatives to car usage. According to Steemers (2003), "the private vehicle typically consumes more than twice the energy per passenger per kilometre than a train, and almost four times that of a bus […]." Brown et al. (2009) estimate that per capita carbon emissions from highway transportation and residential energy use could be cut in half by increasing US urban densities from 0.2 to 6.7 persons per developable acre. However, Newman and Kenworthy (1989) point out that traffic speed in the denser inner cities is generally lower which lowers gasoline consumption, but congestion and stop-and-go traffic in cities might just have the opposite effect.

complex relationship

Closer examination of the evidence suggests that the relationship between urban form and mobility behaviour is more complex and answers are not as clear as they may, at first, seem. Some authors argue that it is not density that matters, but the intensity of land use often expressed as the ratio between population density and number of jobs per unit of area. Newman and Kenworthy (1989) suggest that population and job density are key land use parameters as they together determine how intensively land is used, and are deemed significant to explain the number of trips, distance travelled, and modal split in several empirical studies of land use and travel patterns: "the more intense the land use, the shorter the travel distances, the greater the viability of transit […], the greater the amount of walking and biking, the higher the occupancy of vehicles and, overall, the less need for a car."

Similarly, findings show that a diversity of services and facilities in close proximity alters travel patterns (David Banister, 1996; Stead & S. Marshall, 2001). There is broad consensus that the provision of local facilities and services reduces travel distances, but less agreement that it also alters modal split and, hence, promotes less energy intensive modes, namely walking and cycling.

Impact of Socio-Economic Factors on Mobility Behaviour

The most contested issue, however, is the influence of personal and household socio-economic characteristics on travel distance and modal choice. There are several reasons why there is little general consensus on the effect of socio-economic factors on mobility behaviour.

contradictory findings

First of all, findings are contradictory as to whether personal and household characteristics are more important determinants of travel than land use characteristics. Bento et al. (2005) find that "household characteristics have a stronger influence on commute-mode choice than urban-scale characteristics." Banister (1996), while acknowledging the influence of household income, car availability, and respondent sex, also argues that the role of urban planning in contributing to reduced transport energy consumption is largely underplayed. He finds that lower residential population densities are associated with higher energy consumption patterns and that much of the difference in energy consumption is due to journey distance.

However, while there is emerging consensus in scientific literature that personal and household characteristics are more important determinants of travel than land use characteristics, dispute remains as to the range of impact, in particular on modal choice and on travel distance. One important observation in this context is that land use characteristics become more important at an area level rather than at an individual level (David Banister, 1996).

different measures used

The second reason for contradictory results in research pertains to the use of different measures for the same variables and to different statistical methods. Different definitions of density (resident population, resident employment density, workplace population, etc.), different data sources (national, regional, city-wide, etc.) and measurements for "travel" (journey-to-work, all trips, etc.) account for different outcomes and for the fact that results are not unconditionally transferable to other countries or regions.

Stead and Marshall (2001) review a very large number of studies on urban form and travel patterns over 20 years and come to the conclusion that findings are not only sometimes contradictory, but on the whole not easily comparable. From the review of literature they identify 11 types of socio-economic factors: income, car ownership and availability, possession of drivers' licence, working status, employment type, gender, age, household size and composition, level of education, attitudes, personality type. They conclude that, "[t]he variation in socio-economic factors increases the difficulty in establishing the effect of land use characteristics on travel patterns, and adds complication to the comparison of travel patterns in different areas. […] [Furthermore,] these eleven types of socio-economic factors are interconnected, and it is often difficult to separate the effect of one from another (i.e. they are often multicollinear)."

limited interpretability of results

Thus the third explanation for contradictory findings in research concerns the limited interpretability of results due to the difficulty of establishing causality of the relationships even when correlation is high (Stead & S. Marshall, 2001). Correlation may identify a link between variables, but this link may or may not be direct. Income, for example, is linked to the choice of mode for commuting but also to land use patterns as income is also reflected in the choice of family home. This may explain some of the variation in travel patterns in different locations. Like income, car ownership increases travel time and total travel distance, but car ownership is also linked to land use patterns as higher density areas tend to have lower levels of car ownership. The most commonly employed method to hold socio-economic variables constant is the multiple regression analysis, which, however, does not allow the identification of causal relationships. Multivariate analysis is one statistical technique that can provide a better understanding of the interrelations between variables. However, few studies apply a multivariate analysis which is one of the reasons why empirical research remains inconclusive.

4.5.1.2 Methodological Approaches

Handy (1996) defines five basic research methodologies commonly employed in studies on the link between urban form and travel behaviour:

simulation studies

Simulation studies: they assume certain relationships between urban form and travel patterns and then use these assumed relationships to predict, instead of empirically test, the implications for travel of alternative forms of development. Lefèvre (2009) distinguishes between three families of models: the "Urban Transportation Modelling System" (UTMS), the "Discrete choice model" (DCM) and the Land Use and Transport Model" (LUTM). An example of the latter is the "Metropolitan Activity Relocation Simulator" (Pfaffenbichler, 2008), a model that simulates the interaction between land use and transport which was developed at the University of Technology of Vienna.

A simulation study is that of Hankey and Marshall (2010). They examine urban growth patterns for 142 US cities during 1950–2000 and predict six plausible urban expansion scenarios for 2000–2020 estimating the greenhouse gas emissions from passenger vehicles in these urban areas for each scenario.

Friedwagner et al. (2005) apply a traffic model and add data from a household survey to determine the share of energy consumption relatable to spatial development. In a first step, the authors take stock of the traffic and settlement development of the past 10 years in 4 Austrian communities and compare the status quo to a hypothetical development which is less space consuming. In a second step, this development is modelled and the traffic generated in the alternative scenario is determined. This approach gives a very realistic picture of the energy efficiency potentials that a change in spatial practices could tap. However, the drawback of the method is that the model must represent the real world situation very accurately, which requires a lot of input data (not collected on a routinely basis) as well as a big computation effort.

Lefèvre (2009) aims to measure the effects of several urban policy alternatives on energy consumption and carbon dioxide emissions (in the year 2020) that are associated with urban transportation in the context of a developing country city, Banglore/India, by using an LUTM integrated model. It needs data input for the urban sectors "activities", "land", "population", "transportation modes", and "road network". Lefèvre claims that the advantage of simulation for the analysis of relations between the transport system and the land uses system is that it allows transferring the observed behaviour to unknown situations and that it yields quantitative conclusions, while empirically testing people's preferences and behaviour produces detailed and reliable results which are, however, valid only for existing situations and are therefore not suited for the assessment of novel and untested policies. The author defines three scenarios (one of which is business-as-usual) as a combination of the three levers "investment in transport infrastructure" (building of metro-line), "land- uses regulation" and "pricing policy". Important conclusion from his study is that, "the energy savings obtained from the integration of transport policies and land-use policies are significantly larger than those obtained from a transport investment alone" and that with a mix of land use and transportation policy, "a stabilization of energy consumption and carbon dioxide emissions is possible."

aggregate analysis

Aggregate analysis: these studies use data or analysis at the zone, neighbourhood, city or metropolitan area level; rather than individual records researchers analyze aggregate statistics.

Aggregate studies are the largest segment of research on the link between urban form and travel patterns:

'Urban form' is usually characterized on an aggregate level, e.g., for a neighbourhood as a whole, but certain elements of urban form may vary within a neighbourhood and may thus be more appropriately measured at the household level, for example, distance to local shopping.

'Travel patterns' are often used, referring to aggregate-level characteristics of travel, such as mode split or number of trips for a zone, in contrast to 'travel behaviour,' which refers to the choices of individuals and households. Handy (1996) argues that due to the aggregation of patterns of travel, this approach, on its own, does not allow for an exploration

of underlying factors and the mechanisms by which urban form influences individual decisions.
Relationships between variables are typically tested applying a simple or multiple regression analysis.

Karathodorou et al. (2010) formally test the relationship between urban density and fuel demand, decomposed into car stock per capita, fuel consumption per kilometre and annual distance driven per car per year, and explicitly estimate elasticities of fuel demand with respect to urban density. They employ a fuel demand model using aggregate city level data to represent urban density and decompose urban fuel demand per capita as the product of car ownership per capita, fuel consumption per km, and annual distance driven per car, with each component specified as a function of urban density. The finding is that urban density indeed affects fuel consumption, however, mostly through variations in car stock and in distances travelled, rather than through fuel consumption per km.

disaggregate analysis

Disaggregate analysis: they use data, such as socio-economic and travel characteristics, and analyse them at the level of the individual or household, thus accounting for variations within a zone or neighbourhood; data on household travel are usually collected through household travel surveys; Analysis of variance or regression models are employed to test the strength of the relationship between socio-economic, urban form and travel characteristics. However, often these studies use a mix of aggregated and disaggregated data, for example, on urban form.

One example would be the already cited study by Permana et al. (2008) that analyses electricity and gasoline consumption patterns related to different land use patterns via household surveys. Additionally, energy use is calculated from the monthly consumption of gasoline or diesel for those having private vehicles. For the respondents who use public transport, the equivalent energy consumption is calculated from travel distance from known origin to destination e.g., from home to work place.

The other two types of analyses, choice models and activity-based analysis, investigate the individual travel choice by either using travel choice models that predict the probability of an individual choosing a particular alternative based on the utility of that alternative relative to others or by looking at the wider context of his daily patterns of behaviour. Urban form factors have usually played a secondary role in these analyses and relationships are not always tested statistically, but may be qualitatively evaluated. These studies remained outside of my consideration.

4.5.2 Assessment Methods for Energy Demand Related to Mobility

LAND USE RELATED energy consumption due to transport demand is a very well-researched field. It must be regarded as the one with the biggest impact on energy consumption connected to spatial planning. In the already cited study by Friedwagner et al. (2005), the comparison of actual urban development between 1991 and 2001 to an alternative and more compact development, involving a theoretical relocation of 9,711 residents, which corresponds to 5% of the population in 4 municipalities in Upper Austria, shows that the impact is huge. An additional mileage of 6.38 Mio km/a and costs of 3,443,610 Euro could have been avoided if these communities had pursued a more compact development.

Ott et al. (2008) reach a similar conclusion and find that, for their 4 case studies, traffic related energy consumption is more than four times higher in the least compact settlement than in the densest one. Differences pertain mainly to urban form, to centrality, and to access to public transport. The more central the settlement, the shorter are individual trips and the higher the share of walking, biking, and public transport in the modal mix. The result of the study also shows that differences are small regarding the number of trips and biggest with respect to average trip length. Also differences in modal split are found to be distinct and systematic.

In a household travel survey for the Federal State of Vorarlberg (Herry, Steinacher & Tomschy, 2008) all communities were classified into 3 categories according to their geographic location and centrality: larger communities (11 municipalities) and smaller communities (23 municipalities) in the conurbation of the 4 largest towns in the region, and municipalities in the periphery (61 municipalities). The results showed that there were fewer differences as one would expect. No significant difference was found regarding modal split; the share of car travel and bus travel was somewhat higher for villages in more peripheral areas. Differences pertained mostly to travel distances and travel time. With decreasing centrality the relative share of trips >10 km increased and was biggest in the small-central communities while the share of trips >20 km was highest for the least central municipalities.

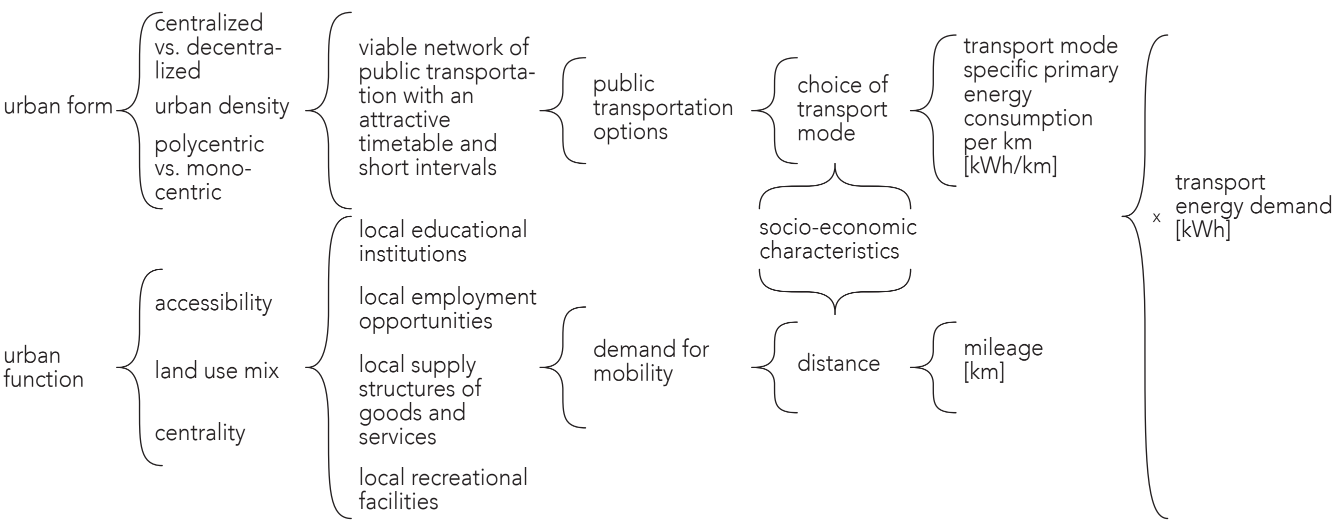
4.5.2.1 Mobility Demand

Mobility demand arises from the necessity to commute to our workplace, to the place where we receive our education, and from the need to travel to reach recreational areas, leisure facilities and supply facilities to meet our basic (daily) needs. The distances we have to cover and the choice of transport mode are strongly related to urban form and urban function. Urban form, on the one hand, translates into travel distance as density and settlement size have an effect on the length of trips and, hence, on transport energy consumption. On the other hand, longer travel distances are associated with a growing proportion of car journeys which also increases transport energy consumption. More importantly, on the level of planning, urban density is also essential for the viability of providing a network of public transportation that offers an attractive transport option as opposed to private motorized traffic. Urban density, therefore, also translates into the choice of transport mode. Modal choice, in turn, has also an impact on the energy consumption per km, as consumption is on average lower for public means of transportation than for passenger cars.

As regards the contribution of urban function to energy demand, the segregation of land uses affects the physical separation of activities and is therefore a determinant of travel demand. Also the provision of local facilities and services, in other words, to the endowment of a community with central facilities, might reduce travel distance and increase the proportion of short journeys capable of being travelled by non-motorised modes (Stead & S. Marshall, 2001). Accessibility, on the other hand, refers to the ease of an individual to pursue an activity of a desired type, at a desired location, and at a desired time by either a public or private, motorized or non-motorized transport mode. Consequently, it combines the notion of centrality with travel time and travel option, or, as Scheurer and Curtis (2007) express it: "Accessibility […] assesses feedback effects between transport infrastructure and modal participation on the one hand, and urban form and the spatial distribution of activities on the other hand."

Our mobility behaviour is, thus, shaped by necessity, but also by personal preferences, attitudes, and income, characteristics often summarized under the term "lifestyle", and is even linked to demographic characteristics like sex and age. From literature we learn that household and socio-demographic characteristics may contribute more to mobility demand than parameters of urban form, however, mostly on an individual level and less on a study area level.

Fig. 16: Factors influencing the energy demand of household mobility behaviour.



4.5.2.2 Data Sources Mobility Behaviour

Tab. 40: Data availability on mobility behaviour of Austrian households.

Data sources:	Data owner	Coverage	Data	Year
Population census, commuter statistic	Statistik Austria	Austria	number counts; commuters/dis-trict	2001
Bundesverkehrswegeplan; survey on mobility behaviour of Austrian households	BMVIT	Austria	various aggrega-ted data on regi-onal and national scale	1995
Household travel survey	Land Oberösterreich	Upper Austria	data on regional and municipal scale	2001
Household travel survey	Land Vorarlberg	Vorarlberg	aggregated data on regional scale	2003, 2008
Household travel survey	Magistrat der Stadt Salzburg Landesregierung Salzburg, Landkreise Berchtesgadener Land und Traunstein	Greater Salzburg	aggregated data on regional scale	2004
Household travel survey	Land Niederösterreich	Lower Austria	aggregated data on regional scale	2003, 2008

Most traffic data are based on (random) sample surveys, some are generated by traffic models, and only few data are collected for the whole (statistical) population.
In Austria, data on mobility behaviour of Austrian households come from various sources. The national population census includes some traffic data on journey-to-work and journey-to-educational institution. Other mobility-related data are collected mostly by the states (*Bundesländer*). This is due to the particular distribution of competences between the federal and provincial governments concerning legislation and enforcement in the field of traffic. For railroads, aviation, and shipping as well as for highways and federal roads responsibility lies with the federal government; all other roads are in the area of responsibility of the state governments[37].

Regional household travel surveys

Therefore, household travel surveys are mostly carried out by the *Bundesländer* within their state territory and data are in the majority of cases available as aggregated statistics. They are collected by drawing a random sample of households; however, the actual sample size is usually much smaller as it is restricted to the number of households that respond and return a valid questionnaire. By extrapolating results it is possible to make inferences on the whole population, yet, it is important to note that "population" is not always defined the same way: in most surveys, "population" includes all residents older than 6 years, in others only "mobile" persons. A mobile person is usually defined as one that leaves home at least once a day thus makes at least on trip. Inconsistencies in the methodology, in the type of data and parameters collected, and in differing definitions and classifications make results difficult to compare. Other problems relate to data restrictions. The latest comprehensive survey on mobility behaviour of Austrian households dates back to 1995 and data are therefore outdated. More recent surveys are only available for certain *Länder* (e.g., Upper Austria, Lower Austria, Vorarlberg), certain regions (e.g., Greater Salzburg region) or certain communities (e.g., Graz, Vienna).

Modal Split Households

Modal split or modal share expresses the distribution of the different means of transport, including walking and biking, as percent of the total traffic volume; in other words, it is the number of trips per mode.

Knowing the modal mix is important for determining traffic induced energy consumption as fuel consumption per passenger-km is different for private and public transport. Furthermore, the modal split is correlated to the density of the public transport network and, hence, to the degree of urbanisation. Statistics show that in densely built-up areas 32.0% of all trips are covered by public transport compared to only 6.7% in sparsely populated areas. In return, in areas with a low population density, 45.3% of all trips are made by car while this share decreases to 27.1% in densely populated areas (Statistik Austria, 2009c).

Comparing the modal mix of different *Bundesländer* or even between different municipalities is difficult due to the lack of a more recent and uniform data base on mobility behaviour of households. As a general statement, it can be said that regional differences in the use of transport modes exist, which may be explained by differences in transport policies and in regional settlement and socio-economic structures. Less dynamic periph-

[37] The distribution of competences is regulated in the Federal Constitutional Law, Art. 10 (9)

eral areas which undergo structural and demographic changes often also have less developed transport infrastructure.

Based on those *Bundesländer* that have comparable data for different years (e.g., Lower und Upper Austria, Vorarlberg, Vienna) a strong increase in private motorized traffic at the expenses of walking can be observed for the past decade. In the same time period, the share of public transport has remained more or less constant. Vienna occupies a rather unique position with a well-balanced mix of public and private transport and a large share of walking. However, a comparison of the 1995 and 2001 data shows that in Vienna the share of walking has also significantly decreased by 6%, while all other means of transport have increased. This leads to the conclusion that private motorized traffic has increased also in those regions for which no recent data on mobility behaviour are available. The 1995 figures are certainly outdated and would have to be revised upward.

Tab. 41: Modal split in Austria and differences between Bundesländer.

Modal split in Austria

	Burgenland	Carinthia	Lower Austria	Upper Austria	Styria	Salzburg	Greater Salzburg	Tyrol	Vorarlberg	Vienna	Austria
	(1995)	(1995)	(2003)	(2001)	(1995)	(1995)	(2004)	(1995)	(2009)	(2001)	
walking	28	24	18	16.6	20	25	11	31	18	27	19.7
biking	5	6	7	6.6	4	8	11	8	15	3	6.7
private motorized traffic	55	59	61	63.2	63	49	60	49	54	36	50.2
public transport	12	11	13	13.6	13	17	18	13	13	34	14.3
sum	100	100	99	100	100	99	100	101	100	100	90.9

Source: BMVIT, 2007 and own compilation; [in %]

gender disparity, age groups and professional groups

Apart from regional differences, other important differences in modal split relate to gender disparity, age groups and professional groups. While, traditionally, women have always been less mobile than men and have a larger share in walking, this gap is gradually closing. The percentage of men and women that dispose of a car is meanwhile almost equal, which can be partly explained by the increase in second cars and is also reflected in general social changes such as the growing number of working women. As regards age and occupation, the age group between 26 years and 55 years, corresponding to the working age population, unsurprisingly has the highest share of car-based trips. This share drops significantly in the age group 66+ years, but elderly people are catching up and are more mobile today than ever before. In Lower Austria, the percentage of car trips in the age group 65+ has increased by 13% between 2003 and 2008. Full-time workers are most dependent on the car (in 1995, 68 % of all trips were made by car), but also other parts of the working population use the car as primary means of transport. Pupils and students have by far the highest share in public transport (36%) (BMVIT, 2007). Aggregated regional traffic data, however, don't reflect the difference between little dynamic areas with aging population and dynamic areas with a higher share of school aged children, all of which has an impact on traffic demand and modal share.

workday and weekend traffic

Another, more important difference in modal split relates to workday and weekend traffic. In most traffic surveys workday and weekend traffic are presented separately with the exception of the Upper Austrian study, which only data collected data on workday traffic. For Vorarlberg and Lower Austria, data reveal significant differences in the workday and weekend mobility behaviour.

On a working day more trips are registered: 9 out of 10 people leave their homes at least once while on Sunday only 8 in 10 do so (Amt der Niederösterreichischen Landesregierung, 2009). Even tough less car rides were registered on Sundays (41% vs. 51% on a working day in Lower Austria) private motorized traffic shows an increase in the modal split. This is owing to the increasing number of passengers per car, meaning that in relative terms more people travel by car (cf. Tab. 41:). Differences in workday and weekend traffic must therefore be taken into account in the assessment of energy demand related to mobility.

Tab. 42: Difference between weekday and weekend journeys. (Amt der Niederösterreichischen Landesregierung, 2009; Herry, Steinacher & Tomschy, 2008)

	Lower Austria (2008)		Vorarlberg	
	working day	Sunday	working day	Sunday
walking	16	26	18	20
biking	7	5	15	14
private motorized traffic	64	67	54	61
public transportation	13	2	13	5

Source: 2008 data for Lower Austria and Vorarlberg; [in %]

Number of Trips, Trip Distance and Duration of Trip

In 1995, the typical daily total trip length in Austria was 29 kilometres and has increased considerably since then.

Tab. 43: Increase in daily trip length.

Daily trip length for Lower Austria (weekdays)	
1995	35 km
2003	42 km
2008	43.5 km

Source: Amt der Niederösterreichischen Landesregierung, 2009

The 1995 data also show that significant differences exist between different regions of Austria. In Lower Austria, Burgenland, Carinthia, and Upper Austria the average daily trip was >30 km, while in Salzburg, Vorarlberg, Styria, Tyrol (and Vienna) average daily trip length was below average, showing a marked east-west disparity. Possible explanations are differences in the level of commuting and population density as settlements in the western Alpine regions of Austria are more compact and less scattered.

Analogous to modal split, trips lengths are also "gendered" and are almost twice as long for men than for women. Just like with modal mix, this gender disparity is slowly reducing as women become more mobile. A comparison of Sunday and weekday total trip lengths, taking the example of Lower Austria, reveals that trip lengths are on average the same. Differences lie in the number of short and long trips: on a weekday, more journeys >20 km are made, while on the weekend journeys between 2.5 and 10 km are predominant (53% vs. 45%). Interestingly, weekend trips by public transportation are on average 13 km longer than on a working day (Amt der Niederösterreichischen Landesregierung,

2009), while the share of public transport decreases on the weekend.
Data for Vorarlberg show that a typical weekday trip is 9.6 km long and a typical weekend trip is 15.7 km long. Travel time, however, stays almost constant (1h 15 min vs. 1h 25 min) for all days (Herry, Steinacher & Tomschy, 2004), which can be regarded as a confirmation of the "constant time budget hypothesis" (Knoflacher, 2006).

Beside data on the number of daily trips and trip lengths, traffic surveys usually also collect data on daily travel time and trip duration. It is worth emphasising at this point that statistics on trip lengths and trip durations are based on personal estimations of the respondents and must be treated with caution. Data on the duration of trips not only give additional information on the mobility behaviour of respondents but are generally considered by traffic planners to be more reliable as respondents find it easier to make judgements on travel time than on distances travelled (Knoflacher, 2006).

Another interesting fact about daily travel time is that it shows little variability and has not much changed in the course of time. In 1995, the average daily travel time budget of an Austrian was around 70 minutes and it still is today. This is not a surprising finding and has often been empirically confirmed. As regards the different Bundesländer, a slight east-west disparity can be found regarding travel time, which might be explained by the higher urban densities in the Alpine provinces of Austria, which reduce travel distances and travel time. The exceptions to the rule are Vienna and Vorarlberg, where trip length and travel time are not correlated. In Vienna, total trip length is shortest while total travel time is longest and vice versa. When we compare different types of trips, such as journey-to-work and school, leisure traffic, shopping trips, etc., we can observe that time budgets are consistently between 20 and 25 minutes for all types of journeys with the exception of business trips, which tend to be longer, and shopping trips, which are below average.

Purpose of Trip

Most statistics distinguish between different purposes of trips, referring to the main reason why a trip was undertaken. The most common classification is the distinction between trips that are made to go to or return from a.) work, b.) school or another educational institution, c.) a business trip, d.) shopping or from e.) running other private errands, f.) bringing and picking up somebody, g.) a leisure activity and h.) other activities.

Tab. 44: Working day trip purposes.

Trip purposes (working day)											
	Burgen-land	Carinthia	Lower Austria	Upper Austria	Styria	Salzburg	Greater Salzburg	Tyrol	Vorarl-berg	Vienna	Austria
	1995	1995	2008	2001	1995	1995	2004	1995	2008	1995	1995
work	27	25	24	17.2	25	28	26	27	27	21	24
education	15	16	11	8.9	15	16	11	16	13	12	15
business	5	9	7	5.2	8	6	6	7	7	8	8
shopping/ other private errands	30	27	26	14.4	30	26	34	27	28	33	30
leisure	20	21	22		18	20	24	21	24	24	21

Trip purposes (working day)											
others	3	3	0	15.3	3	2	0	2	0	2	3
return home				38.5							
sum	100	100	90	100	100	100	100	100	100	100	100

Source: BMVIT, 2007 and own compilation; [in %]

In 1995, 40% of all journeys were journeys-to-work or to-school (or to another educational institution) and some 30% of journeys were shopping trips, which were the shortest of all trips. Where comparable data exist, they show that in relative terms leisure traffic has increased at the expenses of all other purposes except for shopping, which has remained constant over time.

Most surveys also provide a matrix of the various trip types split into the different transport modes in either percent or absolute terms. They are often not directly comparable but given a good indication that modal split per type of trip is less homogenous across Austria than trip purposes as such. Comparing Lower Austria to Vorarlberg reveals significant differences between those two regions. In both regions, car rides to work account for a high percentage of trips. However, the latter has a much higher share of biking to work while in Lower Austria the share of public transport is more than twice as high as in Vorarlberg (25%). The same is also true for commuting to school. Vorarlberg pupils and students are almost twice as likely to walk or bike to school.

Tab. 45: Comparison of modal split per trip purpose (in %).

	Vorarlberg (2008)					Lower Austria (2008)			
	walking	biking	private moto-rized traffic	public transport	others	walking	biking	private moto-rized traffic	public transport
work	7	17	65	12	0	7	7	72	15
education	26	16	15	43	0	18	4	23	55
business	4	5	82	5	3	4	4	84	7
shopping	22	21	51	6	0	21	8	68	3
other private errands	17	15	59	10	0	14	6	74	6
bringing/picking up	22	12	64	3	0	17	5	77	2
leisure	25	13	54	8	0	26	9	58	6
other	36	3	42	10	10				
mean [%]	18	15	54	13	0	16	7	64	13

Source: Amt der Niederösterreichischen Landesregierung, 2009; Herry, Steinacher & Tomschy, 2008; [in %]

commuter traffic

Commuter traffic: Data show that commuting to work makes up for about a quarter of all trips and shows a strong predominance of private motorized traffic over other transport modes. Only for commuting to school or university, public transport prevails.

The Austrian population census 2001 collected detailed information on economic and professional characteristics of commuters and on commuter movements. Commuter movements were collected on the level of political districts allowing inferences about the number of people who commute within the municipality, to a municipality in the same or another district, or abroad. Furthermore, a distinction is made between daily commuters and others, providing a useful picture on commuter traffic related to functional and structural characteristics of a community. However, for the estimation of fuel consumption, this information is not readily usable but must be either translated into distances or linked with additional information.

shopping traffic

Shopping traffic: Statistics show that approximately one third of trips are shopping trips or trips made to run other private errands such as posting a letter, going to the doctor, etc. Here, the car is also the predominant transport mode, but walking and biking also have a high share, pointing at the importance of having basic shopping and service infrastructure within walking distance.

leisure traffic

Leisure traffic: While in Lower Austria leisure trips constitute only 22% (24% in Vbg.) of all trips on a working day, they account for 77% (79% in Vbg.) on a Sunday. Leisure traffic is a very heterogeneous class, but detailed data on leisure time mobility behaviour are scarce. The only survey that collected explicit data on leisure traffic was the Lower Austrian survey of 2008 (Amt der Niederösterreichischen Landesregierung, 2009). It gives some valuable hints as to what kind of activities falls under the heading of "leisure" and about their frequency and trip length distribution.

Tab. 46: Leisure trips on the weekend according to purpose.

Lower Austria: leisure trips on a weekday		
	[%]	km
meeting someone	37	9.9
visiting an event	10	16.1
sports activity	17	8.5
eating out	9	5.2
walking, excursion	13	12.4
others	14	17.4
total		11.7

Source: Amt der Niederösterreichischen Landesregierung, 2009

business travels and holiday trips

Business travels and holiday trips: Data on business travels and holiday travels are collected by the Austrian Statistical Office. However, since we can assume that they are not related or influenced by land use, they remain unconsidered.

4.5.2.3 Data Sources Energy Consumption per Transport Mode

In order to properly determine the energy consumed by transport, the specific fuel consumption of the different transport modes must be known.

Fuel consumption is largely related to friction forces exerting upon a vehicle: rolling-, air-, acceleration-, and gradient resistance. Aerodynamic resistance is one of the most important factors determining fuel consumption as it increases rapidly with increasing speed. It can, for most vehicles, be described by a polynomial function. A decrease in air resistance of 10-20% due to improved aerodynamic design would result in fuel savings of 2-4% and a decrease in rolling resistance of 30% can achieve fuel savings of 2-6%.

As for other aspect of a vehicle's design, the weight of the vehicle is an equally impor-

tant factor. A 10% reduction in weight of a subway train leads to a reduction of fuel consumption of 6.6%. Furthermore, engine technology plays a vital role. Diesel engines are generally 20-30% more energy-efficient than gasoline engines. However, unlike gasoline engines, which are equipped with a 3-way catalytic converter, in a diesel engine the aftertreatment of the exhaust gases is realized by an oxidation catalyst for CO and hydrocarbons and an additional particle filter. Both measures increase fuel consumption by 4%. As NOx emission limits get stricter, internal engine measures for NOx reduction will no longer suffice and the current exhaust treatment will have to be replaced by selective catalytic reduction filters. That means that further optimisation measures will be realized in diesel engines which would go along with an improvement in efficiency of 3-5%.
However, the largest energy saving potential, namely 30%, lies in fuel-economy maximising driving behaviour (Helms, Lambrecht & Hanusch, 2010).

friction forces

To sum up, specific fuel consumption and efficiency potentials are considerably shaped by friction forces acting on the vehicle, by the efficiency of the engine, by the vehicle's design, by the driving style and, most importantly, by the occupancy rate of a vehicles. A meaningful comparison of fuel consumption figures of different transport modes is only possible if consumption is expressed in average consumption per passenger. This requires knowledge on the average number of passengers per transport mode. The average 'occupancy' or 'load factor', however, can vary a lot and can curb or drive up per capita consumption in both private motorized transport and public transportation.

Private Motorized Traffic

Deriving representative values for fuel consumption of passenger cars is complex. There are many factors that influence consumption. For most means of transport, fuel consumption can vary greatly with the various makes and models. Different models of passenger cars can have very different typical fuel consumption/km depending on:

factors influencing fuel consumption

- engine technology;
- engine size and engine temperature;
- gross vehicle weight (including passenger loading/occupancy);
- fuel type (e.g., gasoline, diesel, natural gas, biofuel);
- age and operating condition of the vehicle (e.g., general maintenance, lubrication, tyre pressure);
- road conditions;
- other energy consuming accessories (e.g., air conditioning).

Furthermore, fuel consumption depends on driving style and behaviour. Frequent acceleration and breaking, which is typical for city driving, increases consumption while steady driving saves fuel. It may therefore be argued that the use of average fuel consumption figures to calculate transport energy consumption, without accounting for those other factors that affect transport energy consumption, has limited applicability. However, accounting for each of these parameters for every journey would make any calculation of energy consumption too complex to handle. Average consumption data, on the contrary, represent a reasonable estimate of transport energy consumption under typical conditions (Stead & S. Marshall, 2001).

Since the entry into force of the EU Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions, consumption data must be available for all passenger car models sold in the European Union. Consumption data are determined in a test procedure under standard conditions[38]. The test cycle simulates urban driving and driving at constant speed at 90 and at 120 km/h with sharply defined acceleration and deceleration phases and results are given in litres fuel per 100 km. These values are, however, hardly obtained in reality as test conditions poorly represent average real-world driving conditions.

Data Sources Fuel Consumption Automobile

Fuel consumption measurements for city and highway conditions, obtained under test conditions, are regularly published for all car models sold in the European Union (Deutsche Automobil Treuhand GmbH, 2011). A comparison of fuel consumption of a statistical average diesel-powered passenger car under three standardized conditions (New European test cycle: 57.7 kWh/100 km, city driving: 71.1 kWh/100 km, highway driving: 63.8 kWh/100 km) shows that the test cycle considerably underestimates energy demand (Pucher, 2010). Web-based listings of fuel consumption figures[39] based on the practical experience of drivers reflect real-world driving conditions better than test values; however, they also strongly reflect personal driving behaviour. Very accurate data on Austrian car stock can be retrieved from databases used for emissions calculations.

The Institut für Energie- und Umweltforschung Heidelberg GmbH (2010) uses the composition of car stock for the estimation and comparison of energy consumption and emission factors of different means of transport. For the modelling of energy consumption of passenger cars different vehicle types were defined according to size (compact class <1.4l, medium sized class 1.4-2l, luxury class >2l), drive energy types (gasoline, diesel, LPG, hybrid), emission standards (conventional, Euro 1-5), and load factors (European average of 1.5 persons and 1-5 persons). Furthermore, average speed parameters are defined for each road category (highway: 100 km/h; rural: 75 km/h; urban: 30 km/h) and the extra emissions and energy consumption (+15%) for cold start and evaporation were included in the urban emission factors.

average fuel consumption in Austria

The Austrian Statistical Office also collects data on fuel consumption. Annual mileage and annual fuel consumption data of Austrian households are obtained from the microcensus 2007/2008. They are based on a random sample and then extrapolated (Statistik Austria, 2008). Data are available for Austria as well as broken down by *Bundesland* and distinguish between first and second car. As expected, average mileage of the second car is lower; however, average fuel consumption is identical. In sum, average mileage of a passenger car in Austria amounts to 13,500 kilometres and average fuel consumption per 100 km is 7.8 litres for a car with a gasoline engine and 6.8 litres for a car with a diesel engine. Altogether, this results in more than 3.5 billion litres of fuel consumed by Austrian households per year.

[38] The vehicle performs the test on a chassis dynamometer performing a cold start under reference conditions and driving a standardized European test cycle.

[39] The internet-based data base http://www.spritmonitor.de/ has more than 200,000 entries

Annual mileage and annual fuel consumption of Austrian households for 2007/2008						
type of fuel	number of cars	annual mileage	fuel consumption (final energy) sum	per car in liter	per 100 km	average annual mileage per car
First car						
Gasoline	1,121,953	14,378,935,259	1,120,482,786	999	7.79	12,816
Diesel	1,606,153	26,650,138,195	1,821,013,781	1,134	6.83	16,593
Others	12,950	144,916,151	11,852,081	915	8.18	11,190
Sum	2,741,056	41,173,989,605	2,953,348,649	1,077	7.17	15,021
Second car						
Gasoline	485,525	3,853,309,672	295,151,633	608	7.7	7,936
Diesel	426,539	4,312,245,225	293,196,753	687	6.8	10,110
Others	4,210	24,703,400	1,981,971	471	8.0	5,868
Sum	916,274	8,190,258,298	590,330,357	644	7.2	8,939
Sum						
Gasoline	1,607,478	18,232,244,932	1,415,634,420	881	7.76	11,342
Diesel	2,032,692	30,962,383,420	2,114,210,534	1,040	6.83	15,232
Others	17,160	169,619,551	13,834,052	806	8.16	9,885
Sum	3,657,329	49,364,247,903	3,543,679,006	969	7.18	13,497

Source: Statistik Austria, 2008. Microcensus household energy consumption 2007/2008.

Tab. 47: Annual mileage and fuel consumption of Austrian households for 2007/2008.

Representative statistical figures on the average number of passengers per car are hard to obtain. The following average values were determined for Vorarlberg and Lower Austria:

Tab. 48: Average number of passengers per car. Value for working day: 1.2 passengers/car (NÖ & Vbg); values for weekend and public holidays: 1.6 for NÖ and 1.7 passengers/car for Vbg.

Average number of passengers per car			
	passengers/car	number of days	sum
working day	1.2	247	296.4
weekend and public holidays	1.65	117	193.1
Sum		(296.4+193.1):365 =	1.3

Source: Amt der Niederösterreichischen Landesregierung, 2009; Herry, Steinacher & Tomschy, 2008

The figures for both provinces are similar and in line with the assumed value of 1.3 passengers/car used by Verkehrsclub Österreich in its studies (Verkehrsclub Österreich, 2010). In order to derive a workable parameter for the assessment, the ratio of average fuel consumption/100 km and average number of passengers must be computed to get the average fuel consumption per capita. The distribution of gasoline cars to diesel cars is assumed to be 44% to 56%, neglecting vehicles which run on other fuel types (e.g., natural gas). This results in 0.52 kWh/km/cap for a gasoline car and 0.53 kWh/km/cap for a diesel car.

Tab. 49: Average passenger car fuel consumption per capita.

Average fuel consumption per capita				
	fuel consumption			average no passengers/car
	l/100 km	l/km	l/km/cap	
gasoline car	7.76	0.078	0.060	1.3
diesel car	6.83	0.068	0.053	1.3
Source: Statistik Austria, 2008 and own calculation				

Public Transportation

Obtaining representative data on fuel consumption for the various means of public transportation is far more difficult than getting a reliable and up-to-date data set on fuel consumption for passenger cars. On the one hand, this is related to the fact that, similar to passenger cars, there are numerous models and types in operation. This is true for rail-bound as well as for street-bound vehicles. Statistics on consumption therefore always represent average values aggregated over many different categories of vehicles and must be considered as approximate values.

data availability

On the other hand, data availability for public means of transport is much worse than for passenger cars. Data on fuel consumption are not recorded by the statistical office. For reliable consumption figures, data would have to be collected from each individual public transport provider, which, apart from some exceptions like the Austrian Federal Railways, operate mostly on a regional or local scale. Sources of energy consumption data on public means of transport found in literature are either outdated (Knoflacher, 2006) or based on data from other countries (Ott et al., 2008; Institut für Energie- und Umweltforschung Heidelberg GmbH, 2010, ProBas database).

Primary energy consumption figures depend on the types of vehicles in use and on a country's national mix of electricity production. Electricity production is very country-specific as it is strongly connected to a nation's endowment with own energy resources. The Austrian railways, for example, which operate mostly on electricity from hydropower (89.65%), have a lower non-renewable primary energy demand for electricity than the average Austrian electricity mix supplied to households.

However, it was also argued that differences in final energy consumption are less pronounced as most transport vehicles are supplied by international manufacturers and follow the same or similar registration approval rules, which is particularly true for aviation where there are few internationally operating suppliers (Institut für Energie- und Umweltforschung Heidelberg GmbH, 2010). Larger differences, however, exist for railway transport, where the various railway companies employ different railcars, locomotives, and train configurations and buy energy from different sources.

Data Source Fuel Consumption Public Transport

Data sources for the quantification of energy consumption per passenger-kilometre for public transportation are scarce.

The on-line calculator 'EcoPassenger'[40] commissioned by the International Union of Railways (UIC) enables users to calculate energy consumption and CO_2, NOx, PM, and nonmethane hydrocarbon emissions for any chosen destination. With the tool, individual

40 http://www.ecopassenger.com/

trips by plane, car, and train can be compared regarding their environmental impact and energy demand. The assessment is based on the overlay of information from databases on transport specific emissions, on distances by means of a route planner, and on flight and train timetables. A particular advantage of the calculator is its ease of use and flexibility. Some of the parameter settings can be varied, such as the vehicle class and engine type regarding emission standards for cars and the load factor for cars and trains, distinguishing between average or maximum occupancy. However, the fuel consumption figures actually used are not disclosed and for most parameters averaged data from several European countries are used and it is questionable whether parameters are representative for Austria.

train-specific fuel consumption

As for train-specific fuel consumption, data are collected and updated in the UIC energy and CO_2 database for those member countries that make data available. Consequently, a country-specific fuel consumption value per passenger-km for different train service types is used for eight countries (Belgium, Switzerland, Germany, Spain, Finland, France, United Kingdom and Sweden). For all other countries, a passenger kilometre weighted average value for each service type (highspeed, intercity, and regional/urban) is used, based on the eight country values. The database system also holds data on the stations that can only be reached by diesel trains, which allows the distinction between railway lines that are operated with electrical and those operated with diesel traction. For the load factor the average numbers of six countries are used as default values. The Austrian railway-specific energy mix (89.65% renewables and 10.35% others in 2007) is considered in the conversion from final to primary energy (Institut für Energie- und Umweltforschung Heidelberg GmbH, 2010).

Tab. 50: Average values for specific energy consumption of European trains.

Average values for specific energy consumption of European trains

	Electric (kWh/Pkm)			*Diesel (g/Pkm)*	
	highspeed	intercity	regional/suburban	intercity	regional/suburban
Average	0.070	0.077	1.105	0.205	0.301
	Electric (kWh/seatkm)			*Diesel (g/seatkm)*	
	highspeed	intercity	regional/suburban	intercity	regional/suburban
Average	0.032	0.030	0.035	0.088	0.100

Source: Institut für Energie- und Umweltforschung Heidelberg GmbH, 2010

The second data source on energy consumption per passenger-kilometre used in this study is presented in Tab. 50[41]. Values were calculated based on German data, but have already been used for an Austrian study (Bohunovsky, Grünberger, Frühmann & Hinterberger, 2010) and provide data on the most important means of public transport. The figures are aggregated and averaged values and must therefore be regarded as rough estimations rather than accurate figures. Due to the high degree of generalization it seems valid to also apply them to Austria as they convey a realistic impression of the orders of magnitude but make no claims to accuracy. More accurate values could be obtained by

[41] It can be accessed on the website: www.bus-und-bahn-im-griff.de [accessed 10 June 2011]

adjusting the railway's mix of electricity production, load factors, and specific energy consumption per train type to the Austria situation.

As already said, values are mean values derived from the average energy consumption, converted into gasoline equivalents, divided by the average number of passengers as percent of full load, and are expressed in passenger-kilometres. The energy consumption per passenger-kilometre depends very much on the load factor of a bus or train: a regional train operated at full capacity during rush hour might have a per capita consumption of 1 litre/100 km, while fuel efficiency for a train operated at night might go down to 10 litres/100 km. However, operating the train at a mean capacity of 28%, average fuel consumption per 100 km is assumed to be 5.1 litres for a regional train.

The values given in Tab. 50 are expressed in useful energy consumption and were converted into gasoline equivalents to make them directly comparable to consumption data for passenger cars. In order to convert them to primary energy, they had to be multiplied with the primary energy coefficient of gasoline (1.29[42]) to account for losses in the process from extraction, transformation to distribution.

For trains, primary energy consumption depends a lot on the type of traction, i.e. electrical or diesel traction. In Austria, as much as 75% of all lines are electrified; however, some secondary railways are not electrified and require diesel trains. Energy consumption for the two traction systems is obviously different. For electricity, about two thirds of the energy consumption is required for conversion and upstream process steps, depending on the input mix. For diesel fuel, the final energy use contributes to about 78% of the total primary energy demand. Converting electricity consumption into gasoline equivalents demonstrates the difference between a low final energy consumption of electric drives versus the much higher primary energy consumption. Electricity accounts for high losses in the form of transformation and distribution heat which are somewhat compensated by the higher efficiency of electric engines over combustion engines.

Values for trains equipped with an electrically propelled locomotive given in Tab. 50 express how much gasoline would have had to be burned in a thermal power plant in order to generate the power necessary to propel the train. They represent useful energy consumption thus included the different efficiencies of electric and combustion engines in order to be directly comparable to fuel consumption figures of cars. The calculation steps are illustrated with the example of a locomotive with 5 coaches in Annex I. Values were then converted back to primary energy according to the primary energy coefficients in Tab. 51.

average passenger load factor

As already mentioned, beside the vehicle-specific energy consumption, the per capita consumption is very much dependent on the average passenger load factor. The load factor is expressed as percent of the seating capacity and for urban transportations it is expressed as percent of the places for seating and for standing.

[42] The non-renewable PEC for gasoline in passenger cars was determined in a Swiss study by Frischknecht and Tuchschmid (2008). Data come from the lifecycle database "ecoinvent" and the Swiss average passenger car fleet was assumed.

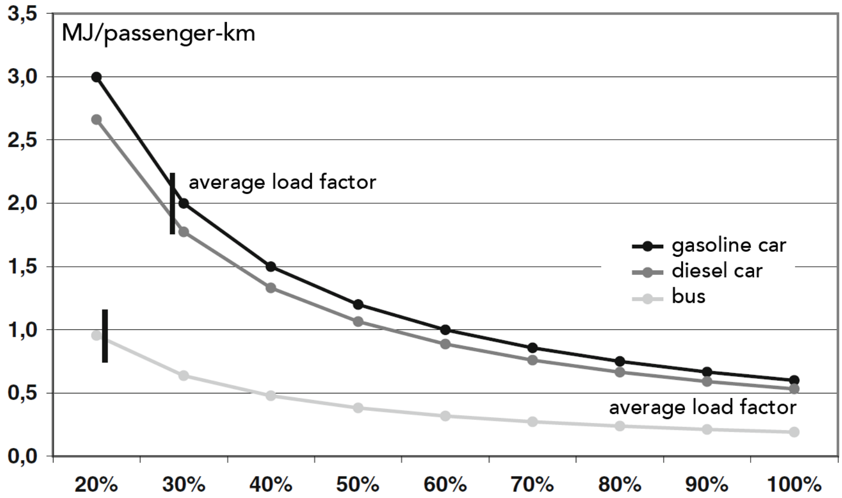


Fig. 17: Specific energy consumption as function of occupancy. (Helms, Lambrecht & Hanusch, 2010)

Under the given assumptions, the energy consumption of an EC train is, in absolute terms, lower than that of the ICE train, but due to the smaller number of passengers per capita consumption is higher (cf. Tab. 50). The figure published by Helms, Lambrecht & Hanusch (2010), however, shows a different picture (cf. Fig. 15). Here, the consumption per passenger-kilometre of the EC train is lower.

Other factors influencing fuel consumption of a train are connected to the trajectory (e.g., height profile of the route, velocity profile, also in relation to the distance between stops, etc.) and to the equipment of the train with energy-consuming appliances (e.g., heating or air conditioning) or energy-recovering devices, such as a regenerative breaking system that is able to return energy to the catenary. Of minor importance for fuel consumption in trains is the additional weight of passengers and luggage, as they account for only a very small part of the weight.

Tab. 51: Fuel consumption conversion factors and specific consumption for different transportation modes.

Conversion factors fuel consumption for public transportation modes into gasoline equivalents

	fuel consumption [l/100 km]	fuel consumption [kWh/100 km]	primary energy consumption [kWh/100 km]	primary energy consumption [kWh/km/cap]	average passenger load factor [%]
Long-distance traffic	Final energy		Primary energy		
ICE train ≤ 200km/h	2.0	16.97	21.89	0.22	48
ICE train > 200 km/h	2.6	22.06	28.46	0.28	48
EC/IC train	1.9	16.12	20.79	0.21	39
Average	2.2	18.67	24.08	0.24	45
Short-distance traffic					
Regional Express (RE)	4.4	37.33	48.16	0.48	20
Regional Bahn (RB)	5.1	43.27	55.82	0.56	20
S-Bahn (suburban train)	3.7	31.39	40.49	0.40	28
bus	2.7	22.91	29.55	0.30	21
metro, tram	1.7	14.42	18.61	0.19	21
average regional trains	4.0	33.94	43.78	0.44	

Conversion factors fuel consumption for public transportation modes into gasoline equivalents					
average urban public transport	2.6	22.06	28.46	0.28	
passenger car (gasoline)	5.97	50.67	65.37	0.65	26
passenger car (diesel)	5.25	52.69	67.97	0.68	26
weighted average passenger car (44% gasoline cars; 56% diesel)	5.57	51.80	66.82	0.67	26

Source: http://www.bus-und-bahn-im-griff.de/interessantes/energieverbrauch_bus_bahn.html and own calculation

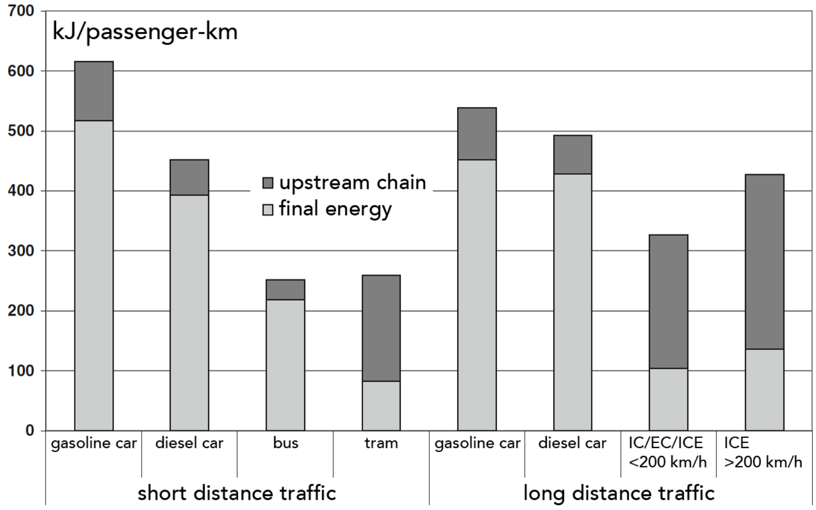


Fig. 18: Comparison of primary and final energy consumption per person km and transport mode (100 kJ = 0.027 kWh). Source: (Helms, Lambrecht & Hanusch, 2010)

4.5.3 Calculating the Primary Energy Demand for Mobility

THERE ARE BASICALLY two approaches how to calculate transport energy demand: by calculating demand from travel distance or from travel time and (average) speed. In either case, it is necessary to know the transport mode as each transport mode for each trip has a specific average fuel consumption per km.

4.5.3.1 Calculating Energy Demand from Travel Distance

In the simplest approach, transport energy use for each trip is calculated by multiplying the distance covered in km with the average energy consumption per km of the transportation mode used.

$$E_{transport} = \sum_i x_i \cdot y_i \qquad (4.47)$$

$E_{transport}$ … total transport energy demand [kWh]
x_i … distance [km]
y_i … energy consumption per km [kWh/km]

The method can be refined by replacing the mean consumption per km by the specific energy consumption depending on mean speed[43]. This either requires additional information on the mean speed of each transport mode or referring to empirically determined values from literature[44]. Even a basic distinction between city driving under free-flow or congested conditions and highway driving could lead to refined results.
For both approaches, the sum of all individual trips and their specific energy demand gives the total transport energy demand of a community (cf. Fig. 18).

Determining Travel Distance

Not all travel surveys contain information on trip length or total travel distance, but instead provide information on travel destinations from a specific source.

travel distance from trip zone data

A possible way of determining distance from such source-destination information involves the calculation of travel distance from trip zone data. This means that the travel distance of each journey is calculated according to the average distances between the origin and destination zone centroids, something that can be fairly easily done with a GIS (geographical information system) or simply by entering source and destination in a route planner[45]. A route planner is implemented, for example, in the EcoPassenger calculator for the calculation of car-based travel distances (Institut für Energie- und Umweltforschung Heidelberg GmbH, 2010). In principle, the tool could be used for the calculation of car-based travel distances. However, the tool was programmed to assign each starting point and destination to a train station or train stop as the calculator accesses information on locations stored in the train timetable database of the UIC. Start and endpoints are therefore always calculated from station to station, even for car rides, and although the calculator allows the definition of stopovers, it is only practical to use it for train trips.

There are a number of studies examining the effect of land use and travel patterns that have relied on trip zone data to calculate travel distances (D Banister, Watson & Wood, 1997). Criticism has been levelled at this method questioning its accuracy as, depending on the size of zones, the actual travel distance may be significantly different to the figure calculated using average centroid distances. Furthermore, in this approach straight-line distances between origin and destination zones are measured rather than actual route distances without accounting for the configuration of the transport network. However, it was also argued that since most studies are comparative the precise calculations of travel are less important than comparable travel distances as long as they have a similar degree of accuracy for each area (Stead & S. Marshall, 2001).

For Austria, an example of source-destination data is the commuter statistic of the

[43] EcoPassenger adds 15% for a cold start and city driving; for city driving with intense traffic, fuel consumption increases by 20–45%.

[44] EcoPassenger assumes 30 km/h for urban traffic, 75 km/h for rural roads and 100 km/h for highway driving

[45] EcoPassenger uses the HAFA timetable information system for bus, train, tram, ferry and air travel used in Austria, among many other European countries. For railway connections it accesses data from the MERITS (Multiple European Railways Integrated Timetable Storage) database containing the timetable data of 32 railway companies. For car routing Navteq data were used.

Austrian Statistical Office. It provides information for each municipality on destinations on the level of political districts. This information is also available (against payment) in the form of a commuter matrix including information on modal split and travel time for each municipality.
In several traffic studies commuter data were used as only travel data, represent all travel purposes. The extent to which studies of single journey purposes (mostly work travel) are representative is highly questionable give that, for example, commuting to work and school accounts for less than half of all trips and total travel distance (Stead & S. Marshall, 2001). Travel data for Upper Austria also contain source and destination information on the most important trip destinations but sometimes mix trips of residents and non-residents, which cannot be easily disentangled.

4.5.3.2 Calculating Energy Demand from Travel Time

The choice of transport mode, income and urban density are assumed to influence the travel time budget of households. Public versus private transport, higher income, and lower density are all associated with higher travel time requirements (Knoflacher, Schopf & Spiegel, 1994).

Assuming that the travel time and average travel speed per transport mode are known for each trip (but the travel distance unknown) then the total traffic volume can be determined as follows:

$$E_{transport} = \sum_i t_i \cdot v_i \cdot y_i \qquad (4.48)$$

$E_{transport}$ … total transport energy demand [kWh]
t_i … time [h]
v_i … velocity [km/h]
y_i … energy consumption per km [kWh/km]

Knoflacher (2006) calculates transport energy demand from average travel speed and travel time arguing that information given by respondents on travel time is usually more reliable than data on travel distances. Drawback of this approach is that average speeds must be known, a parameter which is not usually collected by travel surveys.
The relationship between fuel consumption and velocity can be described by a simple formula:

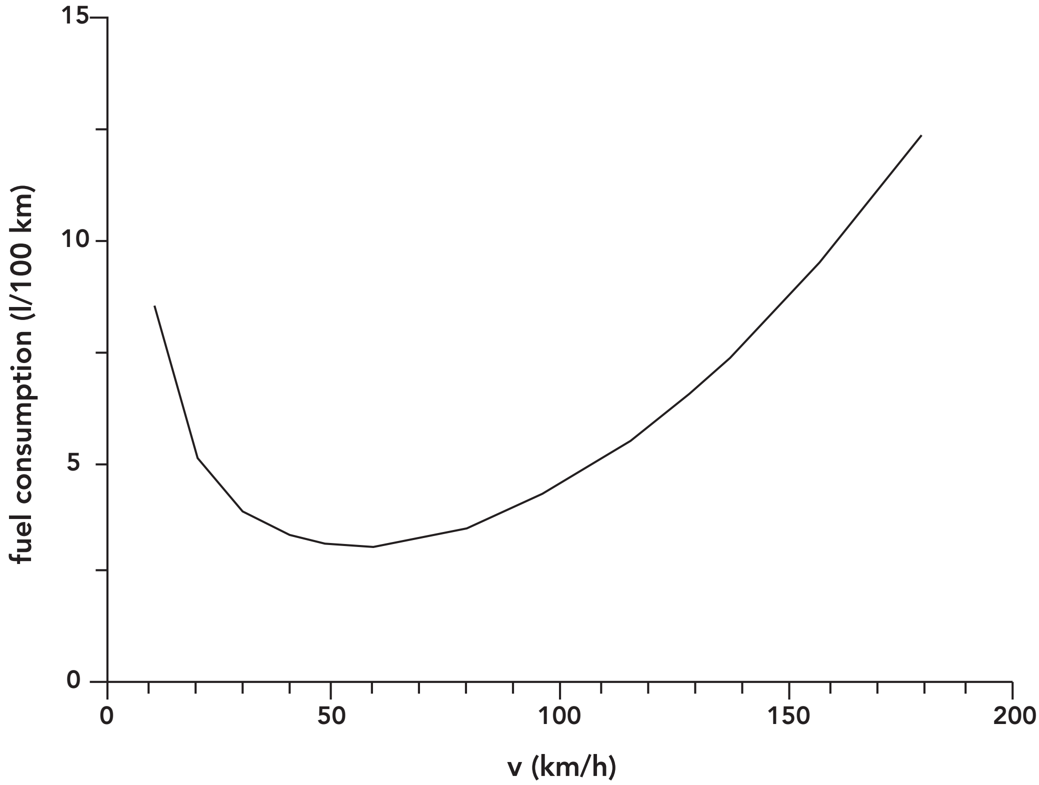
$$E_{car} = a \cdot v^2 + b \cdot v + c + \frac{d}{v} \qquad (4.49)$$

For high velocities the effect of aerodynamic resistance prevails and therefore fuel consumption increases with speed to the square, which can be described by a second order parabola. For low speeds, the proportion of friction losses strongly increases and the share of electricity consumption for auxiliaries (e.g., air conditioning, on-board computer of the car, radio, etc.) and stand-by losses become significant factors that need to be considered. For this purpose the variable “d” is introduced, which is an approximated value proportional to velocity. The mathematical expression decreases with increasing speed.
Parameters a, b, c, and d have to be adjusted for each vehicle model. From that general

formula a typical consumption diagram as a function of velocity can be derived based on measured values.

$$E_{car} = 0.000483 \cdot v^2 - 0.0326 \cdot v + 2.1714 + \frac{66}{v} \qquad (4.50)$$

Fig. 19: Fuel consumption diagram. Values are valid for a warmed up engine; for a cold start 0.1 litre must be added (http://www.chemie.fu-berlin.de/chemistry/general/kfz-energetisch.html)



Another possible approach is the use of the accessibility values described in 4.2.2.2. The data are calculated based on the actual travel time to the nearest regional and supra-regional centre for each 250 x 250 m cell and then aggregated into 30 and 50 minutes catchments. Capacity constraints as well as speed limits are considered in the calculation of the time requirements which makes it a realistic approximation. An intersection of the accessibility raster data set with the line feature of the underlying street network by means of GIS allows determining the path length and, thus, the travel distance. However, the fact that accessibility figures are only calculated for central places sets a limit to this method as journey distances to other places cannot be determined this way.

4.5.3.3 Analysing Results

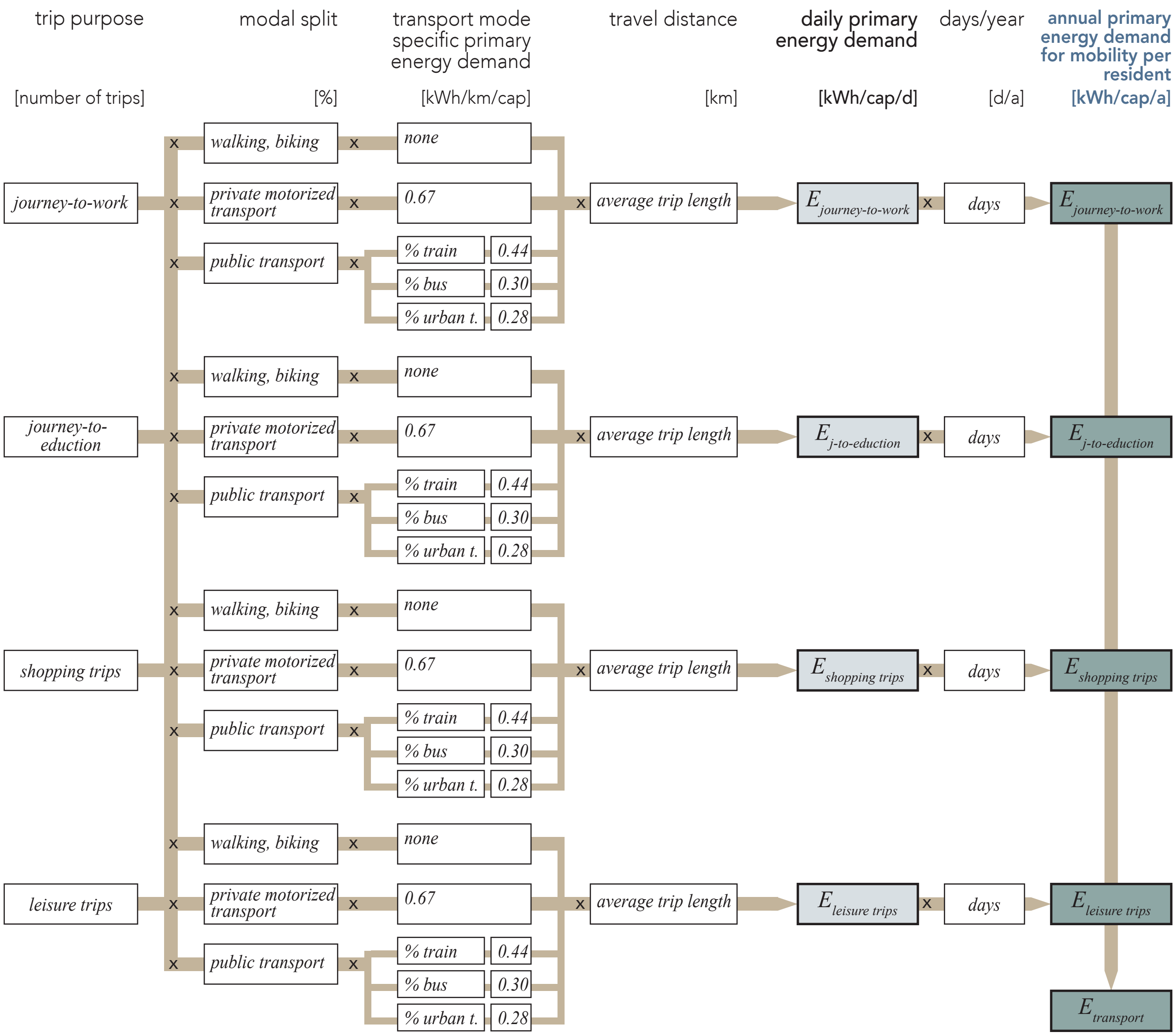
controlling socio-economic characteristics

So far we have determined transport energy demand of communities from the total traffic volume per mode under the assumption that differences in traffic volume must be associated with land use characteristics. From literature we know that personal and household socio-economic characteristics also have an influence on travel distance and modal choice. This influence, however, is stronger at an individual level, when comparing mobility behaviour of different households, while on an aggregated, municipal level land use characteristics become more important. Nevertheless, since household characteristics may have a big impact, they must be factored in to avoid misinterpretations and wrong conclusions.

A possible way out involves the selection of case study areas which have similar socio-economic profiles but different land use characteristics. However, this gives rise to new problems. First of all, it is difficult to hold socio-economic variables constant, especially as there are so many of them. And secondly, dividing communities into categories according to their socio-economic profile, beside the classification into functional and morphological classes, would add even more complexity to the matrix of land use types and the classification scheme would become too difficult to handle.

This means that socio-economic characteristics of different communities must be considered at least before data on energy demand are compared, for example, by comparing their means with a simple statistical t-test, provided the two are normally distributed. If, this way, significant differences in socio-economic profiles are found, results must be interpreted with caution.

Fig. 20: Calculation tree traffic energy demand.



5 Conclusions and Outlook

IN THE PREVIOUS chapter 4, existing energy assessment methods, with special focus on available data sources, were described and discussed. The analysis was split into a separate analysis of the subsystems 'energy demand related to dwelling', 'energy demand related to the provision of technical and public-distributive infrastructure', and 'energy demand for mobility' and a methodology was proposed for each of the three subsystems.

In general, a large arsenal of methods and methodological approaches for the calculation of building, infrastructure, and transport energy use has been developed over time by the various scientific disciplines. The difficulty in choosing the right method relates to finding the optimal trade off between necessary accuracy, on the one hand, and the applicability and comprehensiveness of the approach, on the other hand. Methods for the assessment of building energy demand, for example, need to be transferable to a whole settlement. Therefore, the method must meet requirements in terms of ease-of-use, be manageable for a large amount of data, and data availability, in other words, to content with existing data sources. Naturally, the choice of method must also follow the principles of good scientific practice by ensuring that, in spite of simplifications, results are objective, valid, and reliable.

Furthermore, data sources were discussed as to their quality in terms of timeliness and completeness. Timeliness of the data relates to the fact that data used in the assessment should not be outdated and should possibly be updated in regular intervals. Completeness refers to the availability of data, if possible, for the whole of Austria and the statistical data must be disaggregated by municipality.

Primary Energy Assessment Methods

It has been acknowledged in numerous studies that the effect of land use and urban form on energy demand is strongly influenced by how spatial patterns of form and function are defined and how the system boundary is delineated in terms of time and space.

urban metabolism studies

Urban metabolism studies, for example, define a very broad spatial scope by also accounting for energy imported into an (urban) system in the form of materials and goods thus by looking at the city and its hinterland. However, disparities between urban and rural areas based on the dichotomy between the city and the hinterland have largely disappeared. The old notion of the hinterland that serves the city and supplies it with resources and goods of daily use is no longer true as the hinterland has become global and rural lifestyles and supply structures correspond largely to those of the city. Hug (2002) investigates the Alpine regions of Switzerland and their interactions with the surrounding lowlands and the global hinterland regarding energy throughput and the activity "to nourish" by means of a material flow analysis (MFA). He finds that "the regional degrees of self-sufficiency for energy and foodstuff are relatively low. For both regions the global hinterland is the main supplier for these two mass goods. The physiological net interactions for energy and foodstuff between the regions are not of great significance." It follows that the distance over which materials are transported and the energy stored in imported goods and materials are similar for urban and rural areas. Therefore, a significant difference between dense and dispersed settlements in terms of imported embodied energy is not to expect.

lifecycle analyses

Lifecycle analyses, in turn, widen the temporal scope by examining the energy input for the construction, usage, and disposal of a good or service thus adopt a "cradle-to-grave" perspective. Ott et al. (2008) find that the overall contribution from construction and demolition or disposal to the total cumulative energy demand in buildings and transport is low. In buildings, the main part of the energy is consumed during the use of the building (87-93%), which can be explained by the long lifetime of buildings. In cars, about two thirds of the energy consumed must be allocated to the operation of the car; the share of energy used in car production, for maintenance, and for recycling or disposal accounts for the remaining third. Technical infrastructure can also be characterised by a long lifetime, however, in technical infrastructure, construction and disposal generally consume the bigger part of the energy, at least in low or medium density settlements, while the operating energy demand is low and does not vary with density. Nevertheless, the energy demand for technical infrastructure and utilities (roads, supply and disposal systems) makes up only 2-3% of total household energy demand. Therefore, we can safely assume that, with the exception of technical infrastructure and utilities, including all stages of the lifecycle of a building or car would, while increasing the overall household energy demand by 12 to 15% according to Ott et al. (2008), not significantly alter the result of the comparison between different settlement types. In fact, the authors find that the relative share of energy demand during the use phase is almost identical in the 4 residential quarters of their case study. We can therefore argue that increasing the complexity of the method by applying an MFA or lifecycle approach does not significantly improve the result.

Since the objective of the paper is to develop a method for the quantification of the relative magnitudes of building, infrastructure, and transport energy use in relation to different settlement types, the method must be sensitive to (even the subtle) relative differences between the settlement classes. Furthermore, the method must be suited for a large representative sample and should, in principle, be applicable to any Austrian community thus go beyond the application to few case studies. Consequently, the resulting model must reconcile the need for a simple approach with the necessity to establish relative differences in settlement types, in other words, provide a valid and reliable result.

The outcome of these considerations is a proposed method and model that restricts its focus to the typical average annual household primary energy demand for building and vehicle use, without accounting for upstream processes, and the typical annual primary energy demand of communities related to the provision of technical infrastructure for the total energy embodied in the process from production to disposal. For more specific research questions, this basic model can be extended either by adding new subsystems or by expanding its (temporal) scope to the whole lifecycle of goods and services.

matrix classification for settlements

Therefore, in a first step, a matrix classification for settlements that combines functional aspects of land use and those that focus on morphological aspects of spatial patterns is proposed. This mixed morphological and functional land use parameter draws on the classification of settlements according to 7 structural and density types developed by Doubek and Zanetti (1999) and combines it with the classification of central places developed by Bobek and Fesl (1978), which introduces 6 degrees of centrality. This gives a number of 42 hypothetical combinations; however, high density and low centrality are not likely to coincide which is why the number of classes is more likely to be between 20 and 30 classes (cf. the Swiss classification scheme comprises 13 classes), which should be subjected to practical testing in order to reduce the number of classes to 10 to 15 classes. Since the inventory of central places in Austria was last updated in the 1980s, it is also recommendable to revise the original ranking based on a number of indicator services and eventually introduce some new central facilities and services. This revision can be done by a simple telephone directory search and/or internet inquiry (cf. Weichhart, Fassmann & Hesina, 2005).

energy demand for space heating and technical building services

For determining the energy demand of a building, in particular for space heating and technical building services, numerous approaches have been developed. With the introduction of mandatory building energy performance certificates these methods have become highly standardized. Methods range from very elaborate simulations to simple methods for the rough estimation of energy use in buildings. “Simple” refers not so much to a simplification of the calculation, but rather to the requirement on (the accuracy of) input data. In the presented simple methods, required input parameters are reduced to a minimum. In the case of the method developed by Institut Wohnen und Umwelt (2005), parameters can be determined without inspection of the building, meaning that the analysis can be largely done from the desk using statistical data on the Austrian building stock and default values, e.g., on heat transmittance or on system efficiencies, without the need to acquire additional data. For the calculation of heating energy demand, which depends first and foremost on heat losses due to heat transmission, the building geometry is estimated based on statistical correlation of the surface area of the building envelope with the net floor space of the building. U- and g-values are estimated according to different construction types and building periods and deviations from the characteristic U-values of the construction period of the building due to thermal rehabilitation are also taken into account. In spite of the large degree of simplification, the validity of the statistical correlation method was ascertained by comparing the result of the estimation with actual heating energy demand values. Therefore, it can be safely assumed that it provides sufficiently accurate results for our assessment which aims at comparing building related energy demand of different settlements.

In the simplified methods, annual per capita heating energy demand depends mainly on the size of the floor space per resident, on the construction type (including the type of glazing) and construction period of the house, and to some extent on the building shape. A drawback of the methodology is that the effect of shading on solar gains is only considered in a highly simplified fashion and does not reflect the implications of urban densities on the demand side of building energy use. Highly obstructed urban areas are deprived of useful daylight and solar gains which increases the energy demand for heating and illumination. Furthermore, a high degree of obstruction precludes a residential building from becoming energy self-sustaining through building integrated renewable energy production by, e.g., photo-voltaics. The exact modelling of the shading with the method proposed by the EN ISO 13790 standard requires detailed input on exposure of the building and on the shading cast by the building itself, neighbouring buildings, topography, or vegetation and has to be determined separately for each building. Generalizable findings from research, such as the (near linear) relation between the effect of obstruction and orientation of the building on space heating demand and the relation between building form and heat loss determined by Martin (1972) are a viable alternative to the actual calculation of shading for each individual building.

Furthermore, the aspect of cooling energy demand is not included in the assessment method since few residential buildings are equipped with airconditioning. In future, however, it might be necessary to add space cooling energy demand to the model. In view of increasing summer temperatures due to climate change, the demand for cooling energy is expected to double by 2020 according to "Fachverband Gas Wärme"[46]. From outdoor temperatures of 25°C upwards, the energy demand increases sharply because of the additional operation of airconditioning systems and room ventilators. In Vienna, for example, the additional energy demand on a hot summer day amounts to 5-10%.

obstruction due to high density

Aspects of obstruction due to high density and cooling demand in summer due to heat island effects are important for determining the energy implications of compact densification which are balanced between the benefits from reduced heat losses and the non-benefits of reduced solar and daylight availability. Good arguments in favour of high densities and mixed land use are the viability of an urban public transport system, or the use of district heating energy provision. "For the balance of heat and power to be used optimally the energy demand should not only be localised but also mixed, combining housing with other commercial activities (Steemers, 2003)." Therefore, the role of research in determining when the balance begins to tip in favour of lower densities is evident.

energy demand for technical infrastructure

The implication of urban density on the provision of technical infrastructure and public-distributive services was, to the author's knowledge, mainly investigated in the context of costs incurred for the construction, operation, and maintenance of technical infrastructure and the supply of the population with public-distributive services. However, findings from these studies, for example, regarding the typical infrastructure length or area per capita according to urban density can be used for the calculation of energy demand. The specific annual energy demand for road infrastructure, for water supply and the waste water system, and for electricity, gas, and district heat supply was determined in the already quoted Swiss study (Ott et al., 2008).

energy demand for public-distributive services

More difficult to assess is the energy demand for public-distributive services, such as mobile nursing services and "meals on wheels", collective transportation of pre-school and school children, and garbage collection, which is largely connected to transport energy use. Although a general correlation between density and other urban form parameters and transport distance was found in the study by Doubek and Hiebl (2001), findings also showed that transport distances depend on a combination of factors. Beside density and the structure of the settlement (linear versus radiocentric), transport distances per capita are also dependent on the kind of services a municipality offers, on how transportation is organized, and on the number of clients that make of use a service. It is important to bear in mind that municipalities have considerable autonomy regarding the organisation of community-based social services and waste collection which makes comparison difficult unless standard assumptions are made regarding the type of services offered, the type of vehicles used, and on the ideal-typical relationship between urban density and transport distance.

energy demand for transportation

The land use-energy demand nexus shows the strongest correlation with respect to transport energy use for private mobility. For the calculation of transport (energy) demand, different methodological approaches can be found in scientific literature: simulations of traffic demand and analysis of aggregated or disaggregated data on fuel consumption or travel behaviour. Data on travel behaviour include data on modal split, the number of daily trips, single trip distance or total travel distance, the duration of each trip or total travel time, and the purpose of each trip.

[46] Information taken from www.orf.at (accessed 15 June 2010)

The drawback of simulation studies, while a potent tool per se, is that they predict, rather than empirically test, the implications of urban form and density on travel demand. The danger is that the assumptions made steer the result in a particular direction, leading to a biased result. In order to keep the bias small, any model must represent the real world situation as accurately as possible which requires a lot of input data as well as a big computation effort. Disaggregate analyses, on the other hand, have the known effect that, on the level of the individual or household, socio-demographic characteristics may contribute more to mobility demand than parameters of urban form and land use. The impact of socio-economic household characteristics, however, is less strong on a study area level. Therefore, the first choice of method, also for reasons of data availability, is the analysis of aggregated data.

transport energy demand from travel distance

Transport energy demand can, in principle, be calculated from travel distance or from travel time and (average) speed. In either case, it is necessary to know the transport mode as each mode of transportation has a specific average fuel consumption per km. Specific fuel consumption per passenger-kilometre, in turn, depends not only on the mode of transport, but on a large number of other factors (e.g., cold start, congestion, driving style, weight of the vehicle, maintenance, etc.), notably on the load factor. Load factor refers to the average number of passengers relative to the total seating capacity. Average occupancy data for public means of transport in Austria are not included in official statistics and would have to be inquired at each transport company. Assumptions made on the average occupation of, e.g., a train, are, however, crucial for the specific energy demand per passenger-kilometre and can easily shift the energy balance in favour of the car.

Most mobility surveys collect data on both travel distance and travel time; however, it is important to note that information on trip lengths and trip durations are based on personal estimations of the respondents. Traffic planners therefore generally consider data on travel time to be more reliable as respondents find it easier to make judgements on the duration of a trip than on the distance travelled. Regarding trip length or total travel distance, most surveys present aggregated statistics which provide no indication on the travel demand on the level of municipality. Some travel surveys (e.g., the mobility survey Upper Austria) contain source-destination information on the level of municipality (and/or political district). However, the calculation of travel distance from such source-destination data is subject to a high degree of inaccuracy as the actual travel distance may be poorly represented by trip zone data. In either case, results of the calculation of transport energy demand from travel distance can be significantly improved if driving conditions are considered for the estimation of fuel consumption.

transport energy demand from travel time

An alternative to calculating transport energy use from travel distance and average fuel consumption is the calculation of fuel demand from travel time and (average) speed. The relationship between fuel consumption and velocity can be described by a simple mathematical formula; the major disadvantage of this approach, however, is that data on average speed are not usually collected by travel surveys. Furthermore, differences in daily travel time (e.g., between week day and weekend or between urban and rural areas) are much less pronounced than difference in travel distance, even though public versus private transport, higher income, and lower density are all associated with higher travel time requirements. Many travel behaviour studies provide evidence that the daily travel time budget, contrary to daily travel distance, is a near-constant value (around 1.25 to 1.5 hours/day).

In either case, it is essential to consider personal and household socio-economic characteristics in the interpretation of results as they knowingly have a big influence on travel distance and modal choice. Without the control of these parameters, results may lead to the erroneous conclusion that differences in traffic volume and transport energy demand of communities must be associated with land use characteristics.

Data Sources

The Austrian Statistical Office, which is responsible for the centralized collection, management, and storage of statistical data, and the Austrian Federal Office of Metrology and Surveying, as the largest owner of land surveying data in Austria, store substantial amounts of data. Parts of the modelling can be based on these existing data sources without the need for additional data collection. However, data sources are often inadequate because data are either only available in aggregated format or are outdated. While most of the data are publicly available, it is important to note that some data, in particular land surveying data, are only available against payment. On a general note, all data sources must be critically scrutinised regarding their quality and representativeness before their use in the assessment.

primary energy coefficients

In section 3.1.4, it was argued that for a meaningful result it is necessary that all energy flows are converted to primary energy. The conversion into primary energy makes possible the simple addition of different types of energies, such as thermal, mechanical, and electrical, because primary energy includes the losses of the whole energy chain, including those located outside the system boundary. Local conditions, e.g., for electricity generation and fuel supply, lead to different national primary energy coefficients (PEC). However, valid primary energy coefficients from reliable sources are difficult to obtain for Austria. For heating fuel (e.g., heating oil, gas, fuel wood, wood chips, and wood pellets), the calculation of primary energy coefficients for different energy carriers is defined in EN 15603 (Austrian Standards Institute, 2008c) and for district heat it is defined in EN 15316-4-5 (Austrian Standards Institute, 2007b). For motor fuel, to the author's knowledge, no such standard exists and coefficients found in literature vary greatly. This can be explained by the different assumptions made regarding the energy overheads of extraction to point of use and can be related to the fact that some authors refer to useful energy by including the conversion efficiency of the engine in the PEC. Different conventions exist not only regarding energy overheads which must be included, but also concerning the heating value (upper or lower heating value) on which the calculation is based.

Additionally, a distinction is made between primary energy factor, including all energy overheads, and non-renewable primary energy coefficient, excluding the renewable energy component of primary energy. The two values may differ considerably and should not be intermingled which is why it must be clearly stated according to which convention the PEC was determined.

Since we are interested in the non-renewable part of energy consumption, the choice fell on the use of the non-renewable PEC. The values for heating fuel in Tab. 51 refer to non-renewable primary energy and were calculated following EN 15603; the values for motor fuel were taken from a Swiss publication.

In any case, PECs which were determined for other countries must not be uncritically adopted as there are considerable country differences. Especially regarding electrical power generation the origin of the primary energy carriers, transport routes, properties of the Austrian grid, and the particular Austrian energy mix have a strong influence. Furthermore, the energy mix changes every year resulting in a different PEC for different periods of time and the international trade of electricity since the liberalisation of the energy market makes the determination of the PEC for electricity even more difficult.

To sum up, PECs have to be carefully chosen, bearing in mind that the assumptions made have significant impact on the result.

energy indicator of a settlement

The energy indicator of a settlement was defined in the paper as the total primary energy demand per resident for dwelling, infrastructure, and transportation. Most reliable data on the number of residents comes from the Central Register of Residents which lists all permanent residents and residents which have their secondary residence in the municipality. Secondary residence doesn't count as full residence but shall be weighed.

For determining parameters of urban form and urban function different data sources are available depending on the type of indicator used. As pointed out in section 4.2, a matrix classification for settlements was proposed that combines functional aspects of land use, i.e. the number of central facilities, and morphological aspects of spatial patterns, such as density and urban form. Urban density was defined as the number of residential units per hectare net building land. Data on the number of residential units can come from the building census and the residential building statistic. The most convenient way of determining the net building land is by means of the so-called Austrian digital cadastral map (DKM). The DKM is composed of the digitalised versions of the municipal zoning plans and stores geographic data on the land use categories 'building land', 'transportation zones', and 'green land'. Nowadays, surveying is done using digital measuring devices. Zoning plans ought to be reviewed every 5 to 10 years, which means that data are not older than that. The downside to the DKM is that access to the digital cadastral map is only granted against payment. Urban form, on the other hand, can only be analysed visually either by using maps, such as the Austrian Map 1:50,000, or (digital) aerial photos, and both cartographic data can be accessed for free on-line.

Land use is operationalized by resorting to the number of central facilities in a municipality. The inventory of central facilities according to the frequency and distribution of indicator services was first carried out in the 1970s by Bobek and Fesl (1978) and revised in the 1980s by the same authors (Fesl & Bobek, 1983). Apart from some subsequent studies in Salzburg and Styria, the 1981 survey remains the only comprehensive inventory of Austrian central places to date. However, central places are subject to continuous change and the original ranking should not to be used unreviewed. Review can be either done on a random basis, by verifying a number of indicator services, and/or by introducing some new central facilities and services. Drawing on the method used by Weichhart, Fassmann, and Hesina (2005), this revision can be carried out by means of a simple telephone directory search and/or internet inquiry. A second drawback connected to the use of the central places inventory is the fact that out of 2,357 Austrian municipalities only 630 municipalities were identified as central places. This means that the majority of municipalities remains unclassified and that the degree of differentiation among the lowest rank of centrality, the villages (*Dorfstufe*), is insufficient. This shortcoming can only be addressed by defining indicator services for a higher degree of differentiation among the lowest rank. Possible examples are the endowment with a primary, secondary school, pharmacy, drugstore, number of supermarkets etc. However, it is important to decrease the hypothetical number of combinations rather than to increase the complexity of the classification scheme. The whole settlement classification scheme should be subject to a preliminary study and practical test.

address-, building-, and housing register

A lot has already been said about data sources for the calculation of energy demand for heating and domestic hot water production. A large amount of data on the Austrian building stock is collected by the Austrian Statistical Office. Data come from different sources: from the building census, microcensus surveys, the residential building statistic, and above all from the address-, building, and housing register ('Adress-GWR' database), which integrates data from all the before mentioned sources and is used for the ongoing documentation of building data. The database covers almost all the required minimum input parameters for the calculation of heating energy demand and energy demand for technical building systems. However, there are two important limitations of the database.

data limitations

First of all, for some features, data are fragmentary. While data copied from the building census, such as the net or usable floor space or the building period, or from the cadastral map, such as the built up area, are near to complete, other data, e.g., on the heating system, are only optional input parameters and as such the data stock is incomplete. This concerns notably data on the heating and domestic hot water system which is not a mandatory input parameter in the data base. An alternative to the use of data on technical building systems from the database are aggregated data from the building census 2001. Regarding data accuracy, it is important to emphasise that not all building features are directly inserted in the database either as numeric value or as value chosen from a selection list. Some features of the building are automatically calculated or retrieved from other databases and if no value exists a default value is set. Area data are recorded with an accuracy of two decimal places.

A second limitation refers to data retrieval. The Austrian Statistical Office and the municipalities (in their domain) have the possibility to generate customized reports and statistics. However, for reasons of data privacy, reports which contain data on individual buildings are not passed on to third parties and data are only provided in aggregated format. This means that 1-to-1 assignments of data on gross floor space, number of storeys, building period, construction type and ground plan type, all of which are minimum requirements for calculating building energy demand, are not possible. Available workarounds or solutions involve the evaluation and subsequent classification of data, particularly of data on the gross or net conditioned ground floor which are rational numbers. However, we must bear in mind that any workaround to the use of highly disaggregated building data must be associated with compromises regarding the accuracy of results. Blanket assumptions have to be made on the ground plan type, the number of directly adjacent buildings, the shape of the roof and whether a building has a conditioned or partially conditioned basement or attic.

Besides, certain input parameters, e.g., on the building geometry, are estimated based on statistical correlation with the net floor space and others, e.g, on heat transmittance, are estimated based on the year of construction of the building. This method was validated against a large sample of measured parameters and has proven to provide a sufficiently accurate first estimate for a building's heating energy demand. Heat transmittance of a building's thermal envelope knowingly is the most important factor influencing a building's heating energy demand. Problems associated with the use of the default U-values presented in section 4.3.2.3 relate to their lack of comparability and to the fact that building periods for which the U-values were defined do not match with the building periods recorded in the building registry. More time and effort should be invested in researching representative and valid default heat transmittance values for Austria.

Data limitations concern information on a subsequent thermal rehabilitation of a building. Information on additional insulation is a necessary input for determining the heat transmittance of the building thermal envelope. However, data on additional structural alterations, including thermal rehabilitation, of buildings built before 2006 are only available per municipality in aggregated form in percent and absolute numbers.

Another useful source of information are geographic data such as the Austrian Digital Cadastral Map and orthophotos as some features must be judged visually. This concerns the groundplan type of the building and whether the roof has dowers which increase the roof area. Furthermore, the proposed method uses several default values, for example, a default coefficient for heat transfer or the heat transfer coefficient for linear (and point) thermal transmittance.

data from lifecycle inventory database

The average annual specific energy demand per length or area for road infrastructure, waste water and water, gas, district heating, and electricity supply was determined in a Swiss study by means of data from a lifecycle inventory database. In reality, energy demand for technical infrastructure depends not only on the length of the network. For example, the specific energy demand for sewer systems and waste water treatment plants is highly dependent on other (technical) parameters, such as requirements on volume and capacity, the relief, or the plant design, etc. The implications of urban density and urban form on energy demand for technical infrastructure have been investigated extensively in the context of costs for infrastructure provision, operation, and maintenance. From these studies, we can draw on data on the idealtypical length of the infrastructure network according to different density classes which, although highly idealised, provide a good estimate. Data on road length can potentially come from other sources: GIS-data from land surveying or from automotive navigation systems, etc. Of course, data can also be directly inquired at the utility companies. Furthermore, most data on road infrastructure refer to road length while the specific energy demand determined for road infrastructure refers to area. Therefore, the length has to be multiplied by the average width of the road category. Average lane width for a residential access road is 7.5 m (2 lanes à 2.25 m + 2 pavements à 1.5 m) and for a municipal road designed for a higher capacity and function a width of 9.1 m (2 lanes à 3.05 m + 2 pavements à 1.5 m) can be assumed.

For any data other than the estimated typical infrastructure lengths, it is necessary to define which part of the entire municipal infrastructure to include in the assessment as not the entire network serves private households. Following Doubek and Zanetti (1999), the relevant infrastructure was defined as the *Innere Erschließung* delimited by the most peripheral buildings.

While the degree of connection to the sewer system and public water supply of private households in Austria is close to 100%, not all households are supplied with gas or district heat. Data on the number of households with sewer connection, water connection, electricity connection, and gas connection and data on the heating system can be retrieved from the address-, building, and housing register.

As already said, the energy demand for public-distributive infrastructure is largely connected to transport energy use. The difficulty in finding appropriate data on the specific energy demand of services such as mobile nursing and "meals on wheels", collective transportation of pre-school and school children, and garbage collection, relates to the fact that transport is organised very differently in each municipality. Among other things, this also concerns the type of vehicles used. While for garbage collection, a standard 3-ax rear loader and the smaller 2-ax rear loader for urban neighbourhoods can be assumed, the type of vehicle used for school transportation depends very much on the required capacities and cannot be generalized. For comparability, many generalizing assumptions have to be made regarding the type of vehicle, its specific energy demand, annual transport requirements including the number of journeys, and the total extent of the route. Similar to the relationship between urban density and technical infrastructure, the relationship between urban density and transport distances can be expressed as an idealtypical function under certain assumptions. From this functional relationship typical transport distances per client can be derived. The relationship is highly abstracted and values are empirically determined based on a small set of case studies. Therefore, they may poorly represent the actual situation and transport requirements of a particular municipality, although the degree of representativeness is arguably sufficient for comparing the energy requirements of different settlement structures. Furthermore, actual transport distances don't depend on density alone but on a combination of factors, notably on the number of users of the service and on how transport is organized. To account for differences in the number of inhabitants in percent of the total population that make use of the service, transport distances were defined for different classes. While figures on the number of children per municipality looked after in kindergarten are collected by the Austrian Statistical Office for each municipality, the percent of outpatient home care and the recipients of "meals on wheels" in a community are not collected. If no data are available, the mean value of 1.75% can be assumed. It is important to bear in mind that the calculated energy demand figure refers to the theoretical demand under the assumed conditions and may only poorly represent the actual consumption pattern. Furthermore, the inaccuracy of the data relates to the fact that tabulated data are taken from the graph in Fig. 19. However, since the contribution of energy demand from social-distributive infrastructure to the total energy demand is small, the range of inaccuracy is within the range of inaccuracy of the whole assessment.

limited data for transport energy demand

Primary energy demand for mobility is well-researched and yet useful data sources are scarce, outdated, incomplete, and inhomogeneous. Due to the distribution of competences in traffic planning between the federal government and the state governments, few traffic data are collected for the whole statistical population. The latest comprehensive survey on mobility behaviour of Austrian households commissioned by the Ministry of Transport dates already back to 1995. The Austrian Statistical Office collected data on journey-to-work and journey-to-educational-institution as part of the national population census 2001. The commuter statistic provides trip zone data for each municipality on source-destinations on the level of political districts. Data are also available in the form of a commuter matrix including information on modal split and travel time for each municipality.

Several *Bundesländer* carried out a household travel survey in the past 10 years and collected data on mobility behaviour within their state territory. However, these data are, in the majority of cases, only available as aggregated statistics and are not disaggregated by community. Inconsistencies in the methodology, in the type of data and parameters collected, and in differing definitions and classifications make results difficult to compare.

Important data that can be retrieved from these household travel surveys are the modal split, travel distance and/or travel time, the number of trips, and trip purpose. Knowing the modal mix is important for determining traffic induced energy consumption as fuel consumption per passenger-km is different for private and public transport. Modal split is correlated with the density of the public transport network and, hence, with the degree of urbanisation, with age, gender, and profession, and with the day of the week (workday and weekend). Differences in modal split between communities are, however, not sufficiently reflected in aggregated regional traffic data.

Daily total travel distance has an obvious impact on energy demand and is knowingly influenced by urban density, gender, and age and is different on a weekday and on the weekend. Furthermore, there are marked regional differences in daily travel distances, which can be related to differences in the level of commuting and in population density. Aggregated statistics reflect these disparities only on a very general level. Daily travel time budget shows much less (regional, gender, etc.) variability. Like travel distance, travel time has increased since the 1990s (from 70 minutes to 80 minutes), however, individual trips remained consistently between 20 and 25 minutes for all types of journeys. Data from travel surveys are based on personal estimations of the respondents and it is important to bear in mind that information on trip lengths is prone to estimation errors. Data on trip durations are generally considered to be more reliable as respondents find it easier to make judgements on travel time than on distances travelled.

Trip purpose is not a strictly necessary, albeit useful information for determining transport energy demand. First of all, it allows the complementary use of, e.g., the commuter statistic together with the regional household traffic data. Secondly, data on the trip purpose, in combination with information on modal split, facilitate the interpretation of results and enable the exclusion of certain trips (e.g., business trips).

The second important data input relates to the specific fuel consumption per person-kilometre for the different transport modes. Determining the (theoretical) fuel demand of a passenger car under specific driving conditions is rather complex as fuel consumption depends on a lot of parameters. However, average consumption figures for gasoline or diesel passenger cars are easy to obtain. Average fuel consumption data for all passenger car models are determined in a standard test procedure and are published. Actual consumption figures under real-world driving conditions are collected in internet databases, and the Austrian Statistical Office also collects data on average fuel consumption of Austrian households in microcensus surveys. Mean fuel consumption figures can be considerably improved by adjusting average values for the different driving conditions (e.g., highway or city driving; free-flow or congested traffic conditions).

fuel consumption individual motorized means of transport

fuel consumption public means of transport

The availability of data on fuel consumption of public means of transport is much worse. Data are not recorded by the statistical office and consumption figures found in literature are either outdated or based on data from other countries. Furthermore, data sources are mostly not very transparent regarding the underlying assumptions. More reliable data could be obtained by directly inquiring data from the different public transport operators; however, this could involve considerable effort as most of them operate on a regional or local scale. A comparison of results of the different available assessment methods and data sources is thus a minimum requirement towards a more reliable result.

As discussed earlier, beside the vehicle-specific energy consumption which, similar to passenger cars, depends on conditions such as vehicle weight, driving conditions, efficiency of the engine, type of fuel etc., specific fuel consumption of public means of transport is highly sensitive to the load factor. Data on the (average) occupancy are equally difficult to obtain as data on fuel consumption and available data from other countries have to be critically examined regarding their representativeness of the Austrian situation. Furthermore, the question arises as to whether average load factors for public transportation are really representative as public transport operates under very different conditions in different regions or municipalities of Austria. In Vienna, for example, 65% of all trips are made by public transportation or by non-motorized modes, such as walking and biking. With an average load factor of 26% (1.3 persons) of a passenger car, the specific energy demand and exhaust emissions are considerably lower for the public means of transport (metro, tram, bus) which have an average daily load factor of 30%[47]. In more thinly populated areas, where public transport modes are operating at a low load factor, the balance can quickly shift in favour of the car. Using the same average consumption figures for all communities might not deliver a very reliable result. Special diligence is also required in the analysis of results as personal and household socio-economic characteristics are known to have an influence on travel distance and modal choice. If these parameters are not controlled, mobility demand might be mistakenly associated with land use characteristics even tough other factors are also at play.

All in all, it is important to note that reported results of the calculation of the specific energy demand for mobility are particularly sensitive to changes in assumptions, that the availability of useful data is restricted and that data must be critically examined. This explains in part why the role of traffic in energy demand related to land use and urban density is unclear and remains a contested issue. Even though the passenger car might have a better energy balance per passenger kilometre under certain conditions, the benefits from public transportation certainly outweigh possible energy savings from private transportation if all negative externalities of private motorized traffic (e.g., noise, land consumption, air pollution, etc.) are factored in.

negative externalities of private motorized traffic

Pischinger et al. (1998) analyse the cost-effectiveness of 26 individual measures for the reduction of traffic energy demand and CO_2 emissions regarding external cost (infrastructure costs, vehicle operating costs, opportunity costs, and negative externalities, such as accidents, noise, emissions, pollution, etc.). They find that spatial planning measures that favour short transport distances and prevent rural sprawl have the best cost-effectiveness ratio. The very positive balance of spatial planning measures is primarily a result of the large cost saving potential of interventions in the field of land use planning. The study, however, also shows that in the short and medium term the energy and CO_2 saving potential of spatial planning measures is low. Other measures targeted at the cost of private mobility have a much larger impact on mobility behaviour and hence on transport energy demand. However, as already said, reduced energy demand is only one positive effect of higher densities and mixed land use.

[47] Information taken from: http://de.wikipedia.org/wiki/%C3%96ffentlicher_Personennahverkehr [accessed 11 Dec. 11]

Conclusions

The set goal of this thesis was to identify aspects of household energy demand that can be clearly linked to spatial structures of landuse and to develop a theoretical model for the assessment of land use and spatial pattern related energy demand. Steps towards this objective included the development of an indicator for urban form and function for the comparison of different characteristic land use patterns in the Austria and the description of assessment methods, input parameters, and data sources regarding availability and data quality in terms of timeliness and completeness.

research questions

Research questions that stood at the outset of this study were formulated as follows:

- What are the implications of land use and spatial structure on household energy demand and how can they be quantified?
- What are the relations between parameters and how can they be formalised in a model?
- What are necessary (and existing) data sources for their quantification?

What can we conclude about the implications of land use and spatial structure on household energy demand, about formalising them in a theoretical model, about quantifying them, and about the availability of data?

working hypothesis

Our working hypothesis implies that land use and spatial structures contribute to household energy demand by increasing the demand for heating, domestic hot water, and illumination, by increasing the demand for public-social and technical infrastructure, and by increasing the demand for (private motorized) mobility. Accordingly, the analysis is split into a separate assessment of the three subsystems of household energy demand: dwelling, infrastructure, and mobility.

As regards dwelling, the type of housing, more specifically, the surface to volume ratio and the floor space per resident, and daylight availability have an impact on the demand for heating, hot water, and illumination and link building energy demand to urban density. Urban density and spatial structures influence energy demand for technical infrastructure as the demand per unit of development rises with decreasing densities. The same is true for the provision and operation of public and social-distributive services, such as garbage collection, municipal school transport, mobile elderly care, meals on wheels, etc. And finally, mobility demand arises from the need to travel, which is strongly related to density and land use. On the one hand, urban density translates into travel distance as density and settlement size have an effect on the length of trips and, hence, on transport energy consumption. On the other hand, longer travel distances are associated with a growing proportion of car journeys which also increases transport energy consumption. More importantly, on the level of planning, urban density is also essential for the viability of providing a network of public transportation that offers an attractive transport option as opposed to private motorized traffic. Modal choice, in turn, has also an impact on the energy consumption per passengerkilometer as consumption is on average lower for public means of transportation than for passenger cars. Regarding the contribution of land use to energy demand, the physical separation of activities is a determinant of travel demand. A local provision of facilities and services is thought to reduce travel distance and increase the proportion of short journeys capable of being travelled by non-motorised modes.

available assessment methods

Available approaches to quantifying energy demand exist for the assessment of building, technical infrastructure, and transport energy demand. The difficulty in choosing the right method relates to finding the optimal trade-off between necessary accuracy and the applicability and comprehensiveness of the approach.

We argue that broadening the spatial or temporal scope of the assessment by taking a material flow or lifecycle analysis approach would disproportionally increase the complexity of the analysis and requirements on data without significantly improving the result. Urban metabolism studies define a very broad spatial scope by accounting for energy imported into an (urban) system in the form of materials and goods thus by looking at the city and its hinterland. However, disparities between urban and rural areas based on the dichotomy between the city and the hinterland have largely disappeared and a significant difference between dense and dispersed settlements in terms of imported embodied energy is not to expect. Lifecycle analyses, in turn, widen the temporal scope by examining the energy input for the construction, usage, and disposal of a good or service. However, findings from literature indicate that, with the exception of technical infrastructure and utilities, including all stages of the lifecycle of a building or car would, while increasing the overall household energy demand, not significantly alter the result of the comparison between different settlement types. Nevertheless, we point out that only a conversion of all energy flows into primary energy allows for the simple addition and comparison of different types of energies, such as thermal, mechanical, and electrical, because of the sometimes significant losses for energy overheads from extraction to point of use. This means that the defined system boundary must be (selectively) extended to include extraction, transportation, and conversion of primary energy carriers into useful energy in order for the assessment to deliver a meaningful and representative result.

Assembling all findings in a simple flow diagram highlights some of the problems with modelling land use related energy demand. First of all, it becomes apparent that the relationship between land use and energy demand is not a simple cause-and-effect relation. Neither mobility behaviour nor choice of dwelling can be purely explained by spatial planning practices and boundary conditions. Energy consumption patterns are knowingly shaped by socio-economic variables such as income or level of education, and by lifestyles and personal attitudes, such as travel behaviour or environmental awareness. Secondly, the relationship is subject to rebound effects. A pertinent example is the fact that as people become more mobile, larger distances are more readily accepted and goods and services are consumed in varying places. Thirdly, differences in per capita household demand between different settlements depend very much on how settlements are classified. Important definitional issues arise from the many different density parameters and possible ways of delineating area. Rural population may dwell in larger (detached single-family) houses, but households are generally larger which overall decreases the living space per capita. Urban population, in turn, has a higher proportion of single households which increases the average per capita living space. Indicators such as residential density (number of residential units per unit of area) or the floor space index (floor area per plot) tend to overestimate differences associated with urban density.

And lastly, the relationship is sensitive to small changes in the input parameters. This mainly concerns technical assumptions regarding energy efficiencies and energy losses but also definitions of the system boundary, especially in the context of defining primary energy factors. It follows that a serious and reliable result can only be obtained through careful modelling and the use of a sensitivity analysis to study the robustness of the result and susceptibility to variations in the inputs of the model.

available data

Data availability is the most serious bottleneck of the assessment and the choice of method is strongly bound to the availability of data in the necessary quality and spatio-temporal resolution. Parts of the modelling can be based on existing data sources without the need for additional data collection. However, data are often inadequate because they are either only available in aggregated format or are outdated. For example, the classification of municipalities according to the number of central facilities is based on old data which need revision before being used to operationalise land use. Data limitations due to aggregated data concerns travel data from household mobility studies and building data. A large amount of data on the Austrian building stock is collected by the Austrian Statistical Office and stored and continuously updated in a central database. However, data retrieval is legally limited for data protection reasons. Any possible workaround to the use of highly disaggregated building data means a compromise regarding the accuracy of results. On a general note, all data sources must be critically scrutinised regarding their quality and representativeness before their use in the assessment. This particularly concerns primary energy coefficients and specific fuel consumption figures per personkilometre for the different transport modes as assumptions made in the calculation of these figures have significant impact on the result of our assessment.

All in all, more groundwork has to be done before the method can be readily implemented. Generally, the different methodological approaches for the assessment of primary energy demand must be validated by comparing results from samples with measured values. Above all, the matrix classification for settlements should be subjected to practical testing and input parameters must be reviewed in order to reduce the number of classes. Also more data have to be collected; this notably concerns data on mobility demand and on specific fuel consumption.

Outlook

testing of proposed method

An obvious next step is the testing of the proposed method. Particular attention must be paid to the analysis and interpretation of results from the model in order to draw the correct conclusions regarding cause and effect. As pointed out in chapter 2, the relation between land use and energy demand is succumb to rebound effects and is sensitive to small changes in the input parameters, in particular those regarding technical energy efficiencies and losses. Furthermore, energy demand is difficult to disentangle from socio-economic variables that influence energy consumption patterns and from lifestyles and personal attitudes. The use of a sensitivity analysis to study the robustness of the result and susceptibility to variations in the inputs of the model is an indispensable requirement for a serious and reliable result. Nonetheless, potential benefits from a quantification of the contribution of land use and spatial patterns on energy demand are manifold. It can deepen the understanding on the interrelation between land use and energy demand and knowledge on energy saving potentials in the area of spatial planning practices and policies. Consequently, a quantification will contribute to policy making in the field of spatial planning, land use policies, and transport management, support the implementation of measures targeted at land use planning and traffic and mobility management proposed in the National Energy Strategy and the achievement of the envisaged energy efficiency goals, and promote a targeted and efficient use of subsidies and financial resources. And finally, a robust basic model will pave the way towards the development of a modelling tool for making future projections on land use related energy demand and for the comparison of different scenarios of technological progress or urban development for different time horizons.

6 Annex

Ad section 3.1.4

Tab. 52: Primary energy coefficients for heating and motor fuel.

Non-Renewable Primary Energy Coefficients (PEC)		
	PEC	assumptions
gasoline	1.29 [1.)]	Based on upper heating value; average Swiss passenger car fleet
diesel	1.22 [1.)]	Based on upper heating value; average Swiss passenger car fleet
heating oil, extra light	1.17 [2.)]	**Extraction and transportation:** PEC = 1.02 for domestic extraction; PEC = 1.051 for Russian oil extraction (50% of Austrian crude oil imports are from Russia and Kazakhstan); 500 km transport from RUS via vessel [0.1144 MJ/tkm] to Triest; 600 km (150 km for domestic oil) transport via pipeline to refinery; energy demand for pumping [0.00177 MWhel/GWh km] **Production:** conversion in refinery [PEC = 1.1], **Transport to end user:** 50% on road [1.32 MJ/tkm] and 50% on rail [0.46 MJ/tkm]
heating oil, heavy	1.15 [2.)]	**Extraction and transportation:** c.f. heating oil, extra light **Production:** conversion in refinery [PEC = 1.086], **Transport to end user:** transport on rail; average transport distance 200 km
natural gas	1.17 [2.)]	**Extraction and transportation, production and gas storage:** Typical origin of gas: 20% inland, 10% Norway, 70% Russia; Domestic gas: PEC = 1.047; Imported gas: 85% from Russia [PEC = 1.07] and 12.5% from Norway [PEC = 1.047]; **Gas storage:** only 60% of stored gas for domestic consumption; **Transportation:** 4663 km (100 km for domestic gas) via pipelines; energy consumption transport [0.00002 kWh/kWh km]
liquified natural gas	1.11 [2.)]	**Extraction and transportation:** c.f. natural gas; **Production in refinery:** [PEC = 1.04]; **Transportation to end user:** Average transport distance 300 km on road; energy consumption transport [1.32 MJ/t km]
hard coal/anthracite	1.05 [2.)]	**Extraction:** extraction in Poland [PEC = 1.03]; **Transport to end user:** transport on rail; average transport distance 1200 km; energy consumption rail transport [0.46 MJ/tkm]
lignite	1.05 [2.)]	**Extraction and transportation:** c.f. hard coal; Note: PEC refers to lignite as used for coal-fired power plants; lignite for space heating is used in the form of briquettes which have a higher PEC = 1.183.)
coke	1.68 [3.)]	Values from 3.)
wood	0.04 [2.)]	**Harvest:** 0.6% of the energy content of the harvested wood from non-renewable sources (diesel); **Processing (chopping) of wood:** 3.3%; **Transport to end user:** 73.4% on road [1.32 MJ/tkm] and 26.6% on rail [0.46 MJ/tkm]; average transport distance 250 km; Note: PEC for wood is strongly influenced by the type of processing. The higher the degree of processing, the higher the PEC. For wood pellets PECs between 1.16 and 1.22 were published.
process waste heat	0.03 [2.)]	**Transport to heat supply system:** energy demand for pumping [0.01 kWhel/kWhth]; Note: Industrial waste heat is a waste product and can therefore be compared to a renewable energy source. To exploit this heat the use of electrical pumps in necessary. The use of process heat is strongly dependent on the plant-specific configuration. Therefore, only the energy demand for pumping was considered.
from waste	0.04 [2.)]	**Processing:** similar to processing of wood, but due to the softer consistency of waste, a reduction of 50% was assumed; **Transport:** no data published for Austria, therefore same assumption as for transport of wood
electricity		**Austrian electricity mix 2009:** hydropower: 52%; small-scale hydro power plant 3%; other renewables: 5%; thermal power plants: 29%; imports: 11%;
Austrian fossil mix	2.97 [2.)]	**Average efficiencies for conversion:** anthracite: 39.2%; lignite: 37.5%; heating oil: 32%; natural gas: 41.3%; Losses distribution: approx. 5.5% of transported energy amount (according to Austrian energy balance)
Austrian domestic production	1.64 [2.)]	No details
UCTE mix	3.32 [2.)]	Average 2006-2008

Non-Renewable Primary Energy Coefficients (PEC)		
	PEC	assumptions
weighted average domestic production and imported electricity from Germany and Czech Republic	2.85 [2.)]	Average 2006-2008
district heat	0.42 [2.)]	For the example of a fictitious 620 GWh district heating system; Heat sources: heat and power cogeneration (heating oil, natural gas, biomass) [85.5%] and process waste heat [15%]; Losses distribution: 9% of transported heat
heating and hot water		Comparison of different systems for residential block in urban area; for the estimation of conversion losses on the user side, typical expenditure factors (efficiencies) were assumed;
heating oil extra light	1.80 [2.)]	e = 1.54
natural gas	1.73 [2.)]	e = 1.48
district heat	0.55 [2.)]	e = 1.32

1.) Source: (Frischknecht & Tuchschmid, 2008) (values from ecoinvent are for Switzerland)
2.) Source: (Theissing & Theissing-Brauhart, 2009)
3.) Source: ProBas-database

Ad section 4.3.2.4

Tab. 53: Default heating and hot water systems according to OIB-handbook.

Default systems for domestic hot water and space heating generation				
Default system	*Standard boiler*	*Low temperature boiler*	*Condensing boiler*	*Combined heating and hot water by gas central heating*
System temperature	90°C/70°C	70°C/55°C	40°C/30°C	70°C/55°C
Building data				
System	Centralised system	Centralised system	Centralised system	Decentralized system, combined heat and hot water
Hot water distribution	Via circulation pipe	Via circulation pipe	Via circulation pipe	No circulation pipe
Heat emission	radiators	radiators	radiators	radiators
Distributing (horizontal) and ascending (vertical) pipes	Unconditioned zone	Unconditioned zone	Unconditioned zone	Unconditioned zone
Stub and connection pipes	Conditioned zone	Conditioned zone	Conditioned zone	Conditioned zone
Installation year of boiler	Same as construction year of building	Same as construction year of building	Same as construction year of building	—
Fittings	uninsulated	uninsulated	uninsulated	uninsulated
Connections water storage	uninsulated	uninsulated	uninsulated	—
Domestic hot water				
Heat emission	Twin lever mixer tap	Twin lever mixer tap	Twin lever mixer tap	Twin lever mixer tap
Heat distribution	Pipes uninsulated	Relation inner to outer diameter of pipes 1:3	Relation inner to outer diameter of pipes 2:3	Pipes uninsulated
Heat storage	Indirectly heated warm water storage	Indirectly heated warm water storage	Indirectly heated warm water storage	none
Heat generation	—	—	—	—

Default systems for domestic hot water and space heating generation				
Space heating				
Heat emission	Radiator valve operated manually	Room temperature control with thermostatic valve	Zone temperature control with zone valves (time controlled)	Radiator valve operated manually
Heat distribution	Pipes uninsulated	Relation inner to outer diameter of pipes 1:3	Relation inner to outer diameter of pipes 2:3	Pipes uninsulated
Heat storage	—	—	—	—
Heat generation	Standard boiler	Low temperature boiler	Condensing boiler	Combined gas boiler
Default system	*District heating*	*Single oven*	*Solar thermal system*	*Heat pump*
System temperature	70°C/55°C	—	—	40°C/30°C
Building data				
System	Centralised system	Decentralised system	Centralised system; combined generation of hot water and space heat	Centralised system
Hot water distribution	Via circulation pipe	—	—	Via circulation pipe
Heat emission	radiators	—	—	Floor heating
Distributing (horizontal) and ascending (vertical) pipes	Unconditioned zone	—	—	Unconditioned zone
Stub and connection pipes	Conditioned zone	Conditioned zone	—	Conditioned zone
Installation year of boiler	—	—	—	—
Fittings	uninsulated	uninsulated	uninsulated	uninsulated
Connections water storage	—	uninsulated	—	uninsulated
Domestic hot water				
Heat emission	Twin lever mixer tap	Twin lever mixer tap	Twin lever mixer tap	Twin lever mixer tap
Heat distribution	Pipes uninsulated	Pipes uninsulated	Relation inner to outer diameter of pipes 1:3	Relation inner to outer diameter of pipes 1:3
Heat storage	none	Directly electrically heated warm water storage	Indirect; solar tank	Indirectly heated warm water storage (heat pump storage)
Heat generation	—		Aperture area 8 m², simple solar panel, orientation south, 40° inclination	Air to water heat pump
Space heating				
Heat emission	Radiator valve operated manually	—	System 1 or 2	Room thermostat -timing and zone control
Heat distribution	Pipes uninsulated	—		Relation inner to outer diameter of pipes 1:3
Heat storage	—	—		Indirectly ; heat pump
Heat generation	District heating	Single oven		—

Source: Österreichisches Institut für Bautechnik, 2007a

Ad section 4.4.3.1

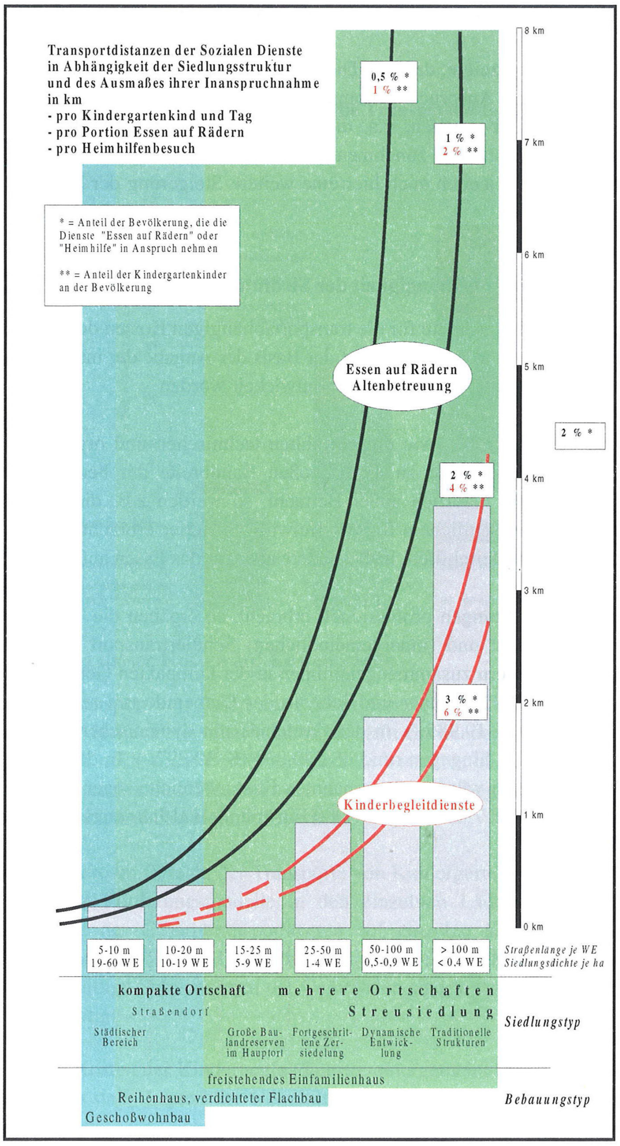


Fig. 19: Typical transport distances for mobile nursing, meals-on-wheels and collective school transport. (Doubek & Hiebl, 2001)

Ad section 4.5.2.3

Tab. 54: Calculation of per capita useful energy consumption.

Calculation for regional train (locomotive + 5 coaches)		
electricity consumption measured at pantograph (=useful energy):	1800	kWh/100 km
primary energy coefficient for electricity:	3.00	
primary energy consumption in kWh:	5400	kWh/100 km
conversion factor kWh to litre gasoline (100 kWh = 11.25 litre gasoline)	0.1125	
primary energy consumption in litre gasoline	607.5	l/100 km
reciprocal value of primary energy coefficient gasoline (1.20)	1/1.20	
final energy consumption in gasoline equivalents:	506	l/100 km
full capacity:	480	seats
per capita final energy consumption at full capacity:	1.05	l/100 km/passenger
average occupation (20%):	96	seats
per capita final energy consumption at average occupation:	5.27	l/100 km/passenger
conversion efficiency of a car engine (30%)	1/1.3	
per capita gasoline consumption (=useful energy) (locomotive + 5 coaches)	4.06	l/100 km/passenger
per capita gasoline consumption (=useful energy) (locomotive + 3 coaches)	4.70	l/100 km/passenger

7 Figures and Tables

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8 Bibliography

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