Doctoral Thesis

Method for Establishing Scalable Load Profiles for Residential and Office Buildings to run an Urban Simulation Environment considering Construction and Mechanical Engineering Technologies as well as the Impact of Social Differentiation

submitted in satisfaction of the requirements for the degree of
Doctor of Science in Civil Engineering
of the TU Wien, Faculty of Civil Engineering

Dissertation

Methode zur Erstellung skalierbarer Lastprofile für Wohn- und Bürogebäude in Abhängigkeit der Bau- und Haustechnik sowie der Einfluss sozialer Differenzierung für eine urbane Simulationsumgebung

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Abstract

The aim of URBEM is to research and develop an interactive environment for analyzing scenarios towards a sustainable, secure supply, affordable and liveable city by the example of Vienna in a holistic and interdisciplinary approach. The interdisciplinary team consisted of 10 PhD students including the supervision of 16 Professors within 5 different faculties along with many experts of the Wiener Stadtwerke Holding AG. The focus was not only to bundle different scientific models associated to the disciplines economy, sociology, building physics, thermal and electrical energy grids, mobility as well as informatics and spatial planning, but also to make them a compatible and holistic completed model within the URBEM simulation environment.

In the context of urban development buildings are not only important due to their considerable contribution to the overall energy consumption, but also due to their significant interaction with human beings and the environment. The results presented in this doctoral thesis show a new established method in order to model buildings and their crucial energy load profile characteristics with respect to certain urban development scenarios. Thus, besides a comprehensive building cluster as well as several HVAC designs, a new method regarding the impact of social differentiation to energy load profiles has been developed. However, simulating all buildings within Vienna would take years, not to mention the lack of necessary data. In order to meet the requirements of an urban decision support tool, all results are provided as scalable energy load profiles to the URBEM simulation environment. Moreover, certain urban development scenarios can be used as initial parameters in order to create time sensitive energy load profiles with respect to the building cluster, the buildings HVAC design and its occupation. Within an hour, all time sensitive energy load profiles are available for either individual buildings, an entire district or even the entire city. The validation procedure concerning the use and accuracy of scalable energy load profiles has shown great accordance at the level of buildings as well as on the city scale. Furthermore, significant load profile characteristics, for instance the age of buildings, its HAVC design or the impact of social differentiated occupation scenarios, can been addressed on a very detailed level.

Zusammenfassung

Das Ziel von URBEM ist die Erforschung und Entwicklung einer interaktiven Simulationsumgebung zur Analyse von Szenarien in Richtung einer nachhaltigen, versorgungssicheren, lebenswerten und leistbaren Stadt, am Beispiel der Stadt Wien. Das Projektteam, bestehend aus 10 Dissertant_innen und 16 Professor_innen aus 5 Fakultäten, sowie eine Reihe von Expert_innen der Wiener Stadtwerken ist sehr interdisziplinär. Dabei werden neu entwickelte wissenschaftliche Modelle aus den Disziplinen Ökonomie, Soziologie, Gebäudephysik, thermische und elektrische Netze, Mobilität sowie Informatik und Raumplanung nicht nur ausgetauscht, sondern innerhalb der entwickelten URBEM Simulationsumgebung zu einem gemeinsam lauffähigen sowie kompatiblen und ganzheitlichen Gesamtmodell vereint.

Gebäude nehmen nicht nur durch ihren hohen Anteil am städtischen Gesamtenergieverbrauch, sondern auch durch ihre ständige Interaktion mit Menschen und ihrer Umwelt eine bedeutende Rolle in der Stadtentwicklung ein. Die Ergebnisse dieser Dissertation zeigen eine neu entwickelte Methode um Gebäude und deren spezifische Energieverbrauchscharakteristiken unter Berücksichtigung ausgewählter Szenarien zeit- und ortsaufgelöst darzustellen. Neben einem umfassenden Gebäudecluster sowie Gebäudetechnikvarianten, wurde auch eine neue Methode hinsichtlich der Unterschiede des spezifischen Energieverbrauchsverhalten durch soziale Differenzierung entwickelt. Die Simulation aller Gebäude in Wien würde Jahre dauern, unabhängig davon, dass die Datengrundlage für detaillierte Simulationsmodelle nicht vorhanden wäre. Um den Ansprüchen eines fundierten Entscheidungsunterstützungstools gerecht zu werden, werden die Ergebnisse als skalierbare Lastprofilsfunktionen der URBEM Simulationsumgebung zur Verfügung gestellt. Über ausgewählte Szenarienparameter werden die Lastprofilsfunktionen initialisiert und als Ergebnis zeitaufgelöste Energieverbrauchsprofile unter Berücksichtigung des Gebäudealters, der Gebäudetechnik und der Nutzung generiert. Die zeitaufgelösten Energieverbrauchsprofile stehen dann für einzelne Gebäude oder aber auch aggregiert für Gebäudeblöcke, Bezirke oder für die ganze Stadt innerhalb nur einer Stunde zur Verfügung. Die Validierung der Methoden hat gezeigt, dass das reale Energieverbrauchsverhalten sowohl auf Gebäudeebene, als auch auf städtischer Ebene durch die skalierbaren Lastprofilsfunktionen sehr gut dargestellt werden kann. Ebenso werden auch alle wesentliche Lastgangscharakteristiken, wie zum Beispiel durch das Gebäudealter, verschiedener Heizungs- und Warmwassertechnologien aber auch durch ein differenziertes Nutzungsverhalten, detailliert abgebildet.

Acknowledgement

First of all, I’d like to offer my special thanks to the entire staff at the research center for Building Physics and Sound Protection at the TU Wien. This friendly environment has been the best environment I’ve could ever imagine to conduct my PhD thesis. Especially the supervision of Thomas Bednar has been a key element within this thesis. His supportive contribution through all stages was helpful, expedient, full of passion and motivating. Thomas Bednar did not only strengthen my technical capabilities in the field of building physics, building simulation and HVAC design but also my behavior and personal role in the context of an interdisciplinary team within the URBEM cooperation. It is also worth mentioning, that Mathias Gladt was very helpful and supportive along the simulation procedure.

Furthermore, I’d like to thank the entire cooperation between the TU Wien and the Wiener Stadtwerke, not only for funding this thesis, but also for the holistic and comprehensive approach within all fields of research. This unique and interdisciplinary set up was inspiring, motivating as well as challenging in a positive way. Moreover, I’d like to thank all of my colleagues within the URBEM project, in particular Sara Fritz, Nikolaus Rab, Nadine Haufe, Dominik Bothe, Thomas Kaufmann, Peter Eder-Neuhauser, Johannes Schleicher as well as Julia Forster. I would also like to thank Karl Ponweiser and Wolfgang Streicher for reviewing this thesis and Gudrun Weinwurm for coordinating the entire interdisciplinary team. Not to mention the “Bundesministerium für Verkehr, Innovation und Technologie – BMVIT” for funding this thesis in the course of the SIMULTAN project.

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Table of Contents

1 Introduction

Vienna, the capital of Austria, will reach a population of 2 million people by 2030, which is an increase by roughly 15% compared to 2014 [MA14]. This fact is challenging the city council of Vienna and the corresponding city planning department, energy suppliers, urban mobility strategies as well as the entire building sector. According to [MER16], Vienna is the most liveable city in terms of “Quality of Living” and achieved the second best score at the “Global Liveability Ranking” conducted by the Economist Intelligence Unit [EIU15]. This leads to the question: How can Vienna grow that fast by maintaining the same high level quality of living?

Based on [WE15], residential buildings contribute with 29% and non-residential buildings with 24% to the final energy consumption of Vienna in 2014. Thus, more than 50% of the entire final energy consumption is needed to heat and power buildings. This leads to the approach that a comprehensive understanding regarding buildings and their individual energy consumption characteristic will be a significant step towards a sustainable and secure urban energy supply.

Global urbanization, sustainable cities and smart cities are polarizing catchphrases and omnipresent. Comprehensive road maps and certain technologies towards sustainable cities already exist, but not yet executed consistently. Besides the general implementation of certain road maps (both national and international), there is an urgent need to develop an appropriate tool for planners, decision makers, politicians as well as researches, to ensure informed and accurate decisions when facing future challenges.

1.1 URBEM

URBEM – entitled as Urban Energy and Mobility System [URB16a] - is an interdisciplinary cooperation instituted by TU Wien and the Wiener Stadtwerke Holding AG (Vienna biggest utility company) [WStW16], established 2013. This comprehensive doctoral course covers not only the interdisciplinary work of 10 PhD students, but also the supervision of 16 Professors within 5 different faculties along with many experts of the Wiener Stadtwerke Holding AG and the City Council of Vienna. The aim is to research and develop an interactive environment for analyzing scenarios towards a sustainable and secure supply, affordable and liveable city by the example of Vienna in a holistic and interdisciplinary approach [URB16a]. The key elements are:

- Business and economic analysis as well as risk management of urban energy and mobility systems (Dissertation #1 / Economics 1 [FRI16] & Dissertation #2 / Economics 2 [RAB16])
- Analysis regarding the energy consumption and mobility behavior for the population of Vienna (Dissertation #3 / Sociology [HAU16b])

- Sustainable methods regarding the renovation of the existing building stock and construction of new buildings (Dissertation #4 / Buildings, which is subject of this thesis)
- Thermal, gas and electrical energy grids (Dissertation #5 / Thermal Energy and Gas [BOT16] & Dissertation #6 / Electrical Grid [KAU16])
- Planning of ICT structures for controlling the urban energy supply (Dissertation #7 / ICT [NEU17])
- Optimized choice of transport in the urban area (work package #8 / Mobility [PFA16])
- Visualization strategies and complex distributed process management (Dissertation #9 / Distributed Computing [SCH16b] & Dissertation #10 / Visualization [FOR16])

Figure 1 provides a holistic overview of all 10 research work packages, respectively to the 10 PhD dissertations within the URBEM environment.

Figure 1: URBEM organization chart [URB16a]. This chart highlights all 10 work packages, respectively the 10 PhD dissertations within the URBEM environment.

1.2 Motivation

Residential and non-residential buildings are omnipresent in cities and are mainly used to accommodate people and to serve as a facility through the entire year. People usually spend a lot of time in buildings, this fact highlights not only the significant interaction between buildings and human beings, but also the huge impact on the well-being of people by buildings. As briefly described in chapter 1 buildings are huge energy consumers. Unfortunately, detailed information's regarding their real energy consumption are very rare. This makes buildings to silent but also to intensive energy consumer and therefore, buildings will play a crucial role towards the aims of URBEM. By considering a simplified approach, the overall energy consumption of buildings can be attributed by 3 criteria's, respectively 3 fields of research:

- Building physics (e.g. age, type of construction, climate, materials, etc.)
- Mechanical engineering in buildings (e.g. district heating, heat pumps, chillers, domestic hot water, etc.)
- Occupation (e.g. office occupation, dwelling, etc.)

This makes the comprehensive understanding of buildings a holistic and interdisciplinary field of research. The aim of this thesis is to gain a much better understanding regarding the interaction of building physics, mechanical engineering as well as the aspect of different occupations by considering a milieu-based approach [HAU16a & HAU16b].

The second aspect of the thesis, which can be considered as both motivation and objective, addresses the issue on how to generate validated energy load profiles for up to 180000 buildings within Vienna [MA11] in order to achieve the aims of URBEM. Therefore, 3 different issues have been identified as key elements in order to conduct this thesis:

- Using detailed building simulation tools might be a time intensive process when considering up to 180000 buildings.
- Furthermore, there is a massive lack regarding necessary building information concerning all buildings in order to feed building simulation tools with appropriate data [ZIE15b].
- Method to distinguish and outline the differences of specific energy load profiles and their crucial characteristics.

In summary, the motivation for this thesis is focusing on how to merge and bundle all interdisciplinary effects in order to run a comprehensive urban simulation environment to serve as a supporting tool for decision makers as explained in chapter 1.

1.3 Definition of objectives

As the interactive URBEM environment serves as a decision support tool for the Wiener Stadtwerke Holding AG, politicians and related stakeholders, the main objectives for this thesis can be summarized as follows:

- Which building types in terms of building physics parameters and mechanical engineering technologies are essential to create load profiles?

- How does a milieu-based approach, considering the method of social differentiation [HAU16a], effects the energy load profiles?
- How do the UBREM scenarios impact the method of creating energy load profiles?

Due to the holistic and comprehensive approach of URBEM each doctoral thesis is subject to individual constraints in terms of interoperability, usability and data management. Besides those constraints future development scenarios, which have been developed within the URBEM [URB16b], serve as initial parameters in order to create energy load profiles for individual buildings, building neighborhoods or even for the entire city. The following scenarios parameters impacts and effects the method of this thesis the most:

- FED / FEC- Development of the Final Energy Demand / Final Energy Consumption for both, heating and electricity
- Building Cluster - Share of the current and future building stock
- HVAC - Share and penetration of current and future mechanical engineering designs
- Milieu - Share of a location sensitive social differentiation considering the milieu-based approach of [HAU16a]

Therefore, the method of creating time sensitive energy load profiles is significantly influenced by those 4 scenario parameters. Furthermore, those parameters have to be used as initial parameters in order to create individual energy load profiles.

1.3.1 URBEM interfaces

As URBEM is an interdisciplinary and comprehensive research project, the organizational setup has to be as clear and simple as possible. Therefore, the process of setting up the data management, communication behavior including all interfaces has been a moderated process from the very beginning. The aim of this process was to ensure a standardized way to interact along with the other doctoral candidates on a regular basis. Therefore, a visual which is addressing all significant dependencies has been created and can be seen in Figure 2.

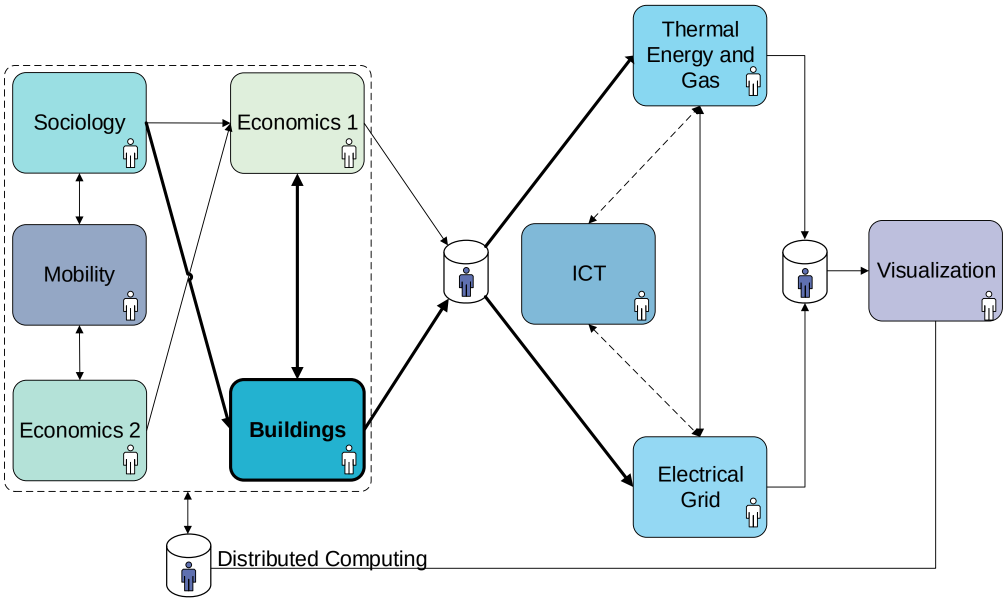

Figure 2: URBEM interfaces and their crucial dependencies, including the significant directories in terms of in- and outputs from the buildings perspective.

The higher level work packages of visualization [FOR16] and distributed computing [SCH16b] are connected with each work package in order to ensure the process of data management and visualization of content. From the perspective of the work package buildings, there is an intensive two-way interaction with the work packages of economics 1 [FRI16] and sociology [HAU16b]. The interdisciplinary interaction between buildings and sociology focuses on a milieu oriented approach in order to distinguish and outline the specific behavior of energy consumption. Based on that, the aim of this interface is to create social differentiated energy load profiles for residential buildings for each milieu (see chapter 3.4). As URBEM is subject to different scenarios (see chapter 1.3), the interaction between the work package economics 1 and buildings focuses on the management and implementation of those scenarios in order to develop a suitable method. The aim is to concretize all scenario parameters in order to use them as initial parameter to run the URBEM simulation environment. A detailed list of all scenario parameters, which effects the method of this thesis the most, is given in chapter 1.3.2. Figure 3 addresses the schematic sequences of scenarios onto the URBEM simulation environment. While the work packages economics and sociology are responsible for the scenario parameters within the URBEM, the work packages mobility, buildings, thermal energy and gas as well as electrical grid have to implement those parameters in each method in order to use them as initial parameters to run the UBREM simulation environment.

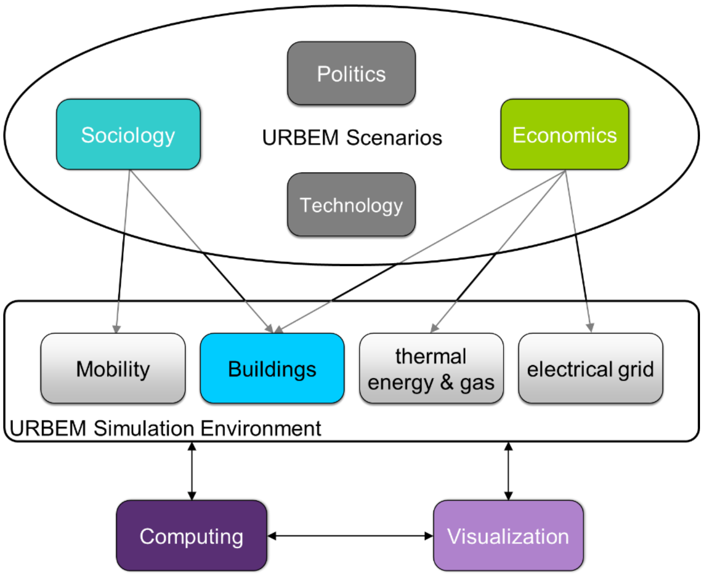

Figure 3: Schematic overview of the sequences regarding the URBEM Simulation environment considering the interaction to the URBEM scenarios.

Based on [SCH16a], the work package of distributed computing leads the entire data management through this process in order to ensure a smooth data handling between all work packages. Additionally, [SCH16b] addresses the issues of interoperability and communication between all interdisciplinary methods by considering each of them as individual domain experts. The last sequence will be the part of visualization regarding coherent results. Example visuals based on early stage dummy data can be seen in [ZIE15b].

1.3.2 In- and output analysis

This chapter addresses a comprehensive summary for all in- and outputs concerning the method of this thesis in order to ensure a sequential interoperability of all interacting working packages within the URBEM simulation environment. Furthermore, all inputs such as scenario parameters have to be used as initial starting parameters and thus, those input parameters effect the developed method within this research significantly.

Table 1: Quantification and specification of all in- and output parameters for work package 4 / buildings.

Name / Type[1]	Specification
I1: Share of each milieu (WP3)	Based on WP3 / Sociology and [HAU16a & HAU16b], the results of the questionnaires are clustered to 10 milieus
I2: Milieu based Attendances (WP3)	Raw data of [HAU16b] concerning the attendances for each milieu clustered by time and day (e.g. working day, week day) – see chapter 3.4.1
I3: Milieu based DHW consumption (WP3)	Raw data of [HAU16b] concerning the domestic hot water behavior for each milieu – see chapter 3.4.3
I4: Milieu based temperature set points (WP3)	Mean values of [HAU16b] for heating temperature set points for each milieu – see chapter 3.4.5
I5: Milieu based cooling behavior (WP3)	Relative mean values of [HAU16b] regarding the use of cooling devices for each milieu – see chapter 3.4.5

Name / Type[1]	Specification
I_6: Milieu based electronic devices (WP3)	Raw data of [HAU16b] regarding the use and amount of electronic appliances (e.g. televisions, cooking appliances, etc.) – see chapter 3.4.2
I_7: Milieu based window opening behavior (WP3)	Raw data of [HAU16b] regarding the opening behavior of windows for each milieu – see chapter 3.4.4
I_8: FED (WP1)	Final Energy Demand for both, heating and cooling, considering the energy boundaries of [IEA13] according to the URBEM scenarios
I_9: Building Cluster (WP1)	Represent the current building cluster of Vienna in terms of age and significant building physics parameters according to [MA11] and [BAU12] with the collaboration of [FRI16] - see chapter 3.2.2
I_{10}: Cluster of different HVAC designs (WP1 & WStW)	Cluster of the current penetration of different HVAC designs in consultation with the Wiener Stadtwerke Holding AG – see chapter 3.3
O_1: Thermal load profiles (WP1, WP5, WP6, WP10)	Time sensitive thermal load profiles taking into account the matrix for all density function – see chapter 3.6.4
O_2: Electrical load profiles (WP1, WP5, WP6, WP10)	Time sensitive electrical load profiles by taking into account the matrix for all density function – see chapter 3.6.4
O_3: Naming (WP1)	All load profiles are subject to an unified naming procedure – see chapter 3.5
O_4: Nomenclature (WP1)	In order to enhance the interoperability regarding the coding, all abbreviations for the naming procedure are standardized and fixed – see chapter 3.5

[1] I … Input; O … Output

The overall aim from the buildings perspective is to create a method to bundle all input parameters into the output parameter O_1 and O_2 with respect to the output parameter O_3 and O_4. The results of the output O_1 and O_2 serve work package 1 as a basis to distribute and initialize all time sensitive load profiles and thus, the aggregated results serve as input parameters for work package 5 and 6. By merging the interactions of Figure 2 with the in- and output analysis given in Table 1, a new visual from the perspective of this thesis is given in Figure 4.

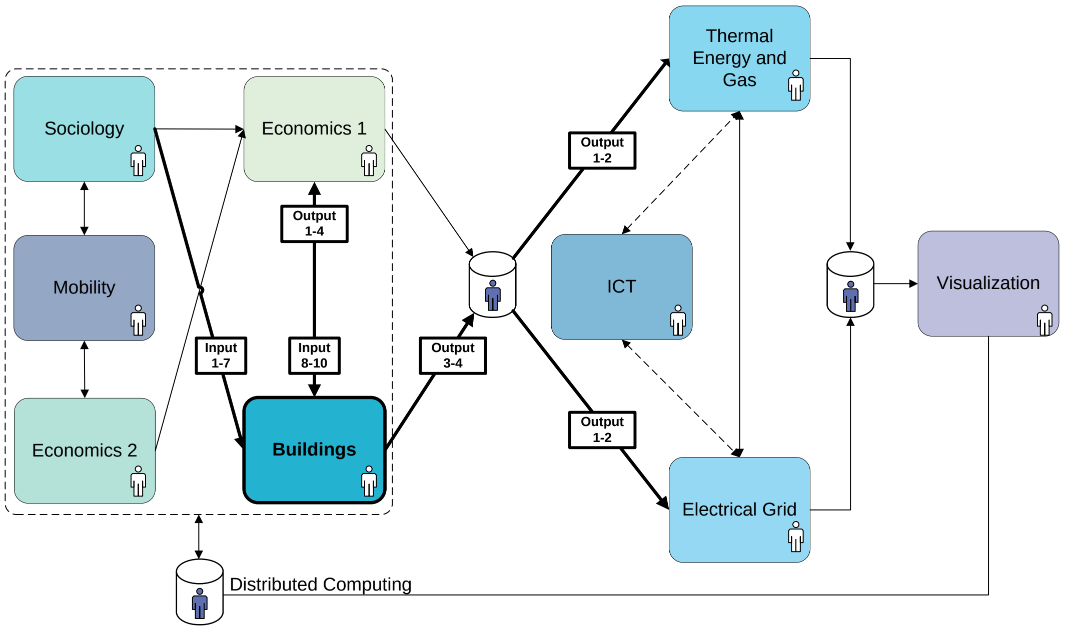

Figure 4: UBREM interfaces with respect to the in- and output analyses from the buildings perspective.

1.4 Research issues

According to the chapters above the overall aims within this thesis can be summarized as follows:

- to establish a validated method of using scalable load profiles for residential and office buildings to run an urban simulation environment considering construction and mechanical engineering technologies as well as the impact of social differentiation,
- to create a method with the capability to emphasize the differences of certain energy load profiles and their crucial characteristics regarding the impact of different scenarios taking into account building physics, HVAC as well as the occupation,
- to provide time sensitive energy load profiles for the URBEM simulation environment without using time intensive building simulation tools,
- due to the interdisciplinary setup of this thesis, an overarching subject is to bundle specific methods and know how related to different technical and sociological disciplines into one validated and consistent method.

2 State of the art

Due to this thesis addresses 3 different interdisciplinary disciplines, the state of the art can be considered as very comprehensive. Thus, major contributions for the specific disciplines are explained in the following. Moreover, certain contributions with a similar interdisciplinary approach compared with the objectives of this thesis are listed in dedicated sub chapters.

Using building simulation tools is very common and popular. The most common building simulation tools have been addressed within the research papers of [CRA05], [WOL08] and [MAI07]. Based on [CRA05], a brief overview of the probably most common simulation engines is given in the following:

- ENERGYPLUS: modular, structured code based on the most popular features and capabilities of BLAST and DOE-2.1. It is a simulation engine using in- and output of text files. Graphic user interfaces, such as DesignBuilder, improve the user experience.
- IDA-ICE: IDA indoor climate and energy - is based on a general simulation platform for modular systems, IDA simulation environment.
- TRNSYS: is a transient system simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components (e.g. a simple pump or pipe, or as complicated as a multi zone building model).
- ESP-r: is a general purpose, multi domain building thermal, inter zone air flow, intra zone air movement, HVAC systems and electrical power flow simulation environment.

[CRA05], [WOL08] and [MAI07] also highlight the strengths and weaknesses of each simulation engine. Usually, the strengths of all simulation engines focus on detailed heat, air and moisture conditions [WOL08], but also on energy issues including the HVAC and thermal comfort [CRA05]. On the other hand, [SAN13] addresses the complicated and time intensive process of setting up the building simulation model in terms of necessary input parameters. This process and the individual efforts only for the setup can take months [SAN13]. Taking into account the objectives within this thesis, detailed simulation tools would be appropriate for individual buildings but not for a building neighborhood or for the entire city. Not to mention the lack of all essential input data in order to setup the building simulation model. In order to give an overview of the strengths and weaknesses of building simulation engines related to the objective within this thesis, the following table has been created.

Table 2: Comparison of the efforts and capabilities considering detailed simulation engines related to the objectives within this thesis.

Specification	Individual building simulation	Needs and capabilities within this thesis
Scope	Individual buildings, or small building neighborhoods [HDZ12]	All buildings within a district or even the entire city
Building physics parameters	Detailed parameters of the entire building construction, occupation and zone modelling	Not or hardly available for individual buildings
HVAC design	Detailed parameters for all mechanical engineering technologies considering individual specification of the building and mechanical setup	General information in order to model specific technologies are available but not related to individual buildings
Setup efforts	Up to a month [SAN13], not or hardly automated. Not appropriate for up to 180000 buildings	Just in time, in order to serve as a decision support tool
Simulation efforts	1min – 1hr (depending on the simulation engine, zone modelling, etc.) for one building. Related to the objectives within this thesis, at least 125 days (only for 1 simulation run)	Taking into account an entire city, e.g. 180000 buildings, roughly 6 hours, in order to serve as decision support tool
Output	Detailed and time sensitive energy load profiles for one building	Detailed and time sensitive energy load profiles for all buildings within a city

The overview given in Table 2 clearly points out the gap. Thus, [AIT13] and [AIT14] focuses to decrease the input efforts for detailed building simulation engines using an automated upscaling approach for buildings envelopes. The upscaling building model gets parametrized with typical parameters related to the buildings age, location, occupation and standard HVAC settings. As far as known this approach is working only for single buildings with a couple of assumptions. In general, a tendency towards the simplification for building simulation applications is definitely recognizable. The proceedings and thematic focus of relevant international conferences, such as the International Building Physics Conference 2015, Building Simulation Conference 2015, CLIMA2016 and SBE2016 even underlines the need for simplification towards the consideration of building neighborhoods and interdisciplinary work.

For instance, [GLA14] presented an algorithm for the automatic reduction of multi-zone models for thermal building simulation in order to reduce the input and calculation efforts. While finite-volume models reflect the reality the best possible way but the computational effort for solving them is considerable and reasonable results for long term simulation can often not be achieved in an acceptable amount of time [GLA14]. Thereby, [GLA14] has developed an enhanced resistance capacity model (RC-model) and thus, makes this model to an integral part of the developed simulation model within this thesis. Furthermore, recently published contributions such as [CSIM16] and [KAM15] highlight the needs towards a holistic city approach, rather than focusing on individual buildings.

[SCH09] and [BAU12] are positive examples in outlining simple and suitable approaches to integrate mechanical engineering parameters into building simulation models. Both contributions are significant in order to integrate a variety of HVAC designs into the simulation model.

As mentioned in chapter 1.3, this thesis objectives are also focusing on the occupation in order to create specific and occupation related energy load profiles. A variety of contributions focus and address only the energy issues balancing at the level of 1 year. Thus, effects and impacts on an hourly basis onto the energy load profile are hardly addressed. A major and well disseminated contribution is [BGW06]. [BGW06] highlights the daily differences regarding the electrical load profile related to residential buildings, office buildings as well as commercial buildings. In the course of [BGW06], up to 8 different load profiles are available. In order to ensure a unified comparability all profiles assume an annual electrical consumption of 1000 kWh/yr. As the milieu based approach within this thesis already anticipate, a detailed understanding of the buildings occupation is going to play a significant role. [PRO09] investigated the general attendances within office buildings and university buildings. The results do not only enhance the understanding of the probabilistic attendance regarding the occupants, but also impact the design of the HVAC designs [HDZ14b]. In order to research the demand side management potential within residential buildings, [GHA11] shows important results regarding the electrical load profiles. [GHA11] considers both, the impact of electronic household appliances but also related to different family types (e.g. singles, couples, full time employed, part time employed, etc.). Moreover, typical electronic appliances (such as washing machines) have been monitored in order to create electrical load profiles based on metered data. This circumstances make the results of [GHA11] highly valuable for further validation purposes. A similar approach compared to [GHA11] is given in [WID09]. Both contribution have used a markov-chain model. According to [RIC10], the markov-chain model is well established in order to create stochastic load profiles. Due to [GHA11], [WID09] and [RIC10] have been focusing only on electronic appliances, the results are only valuable for the validation regarding the electrical load profiles given in chapter 4.2. Furthermore, all results are model based while the results within this thesis are based on the questionnaires of [HAU16b] given in chapter 3.4. Additionally, two research groups from Sweden (Lund Institute of Technology – Department of Heat and Power Engineering) and Scotland (University of Strathclyde – Energy Systems Research Unit) did some valuable preliminary work. [NOR98] derived specific load profiles using the normalized load based on metered data. As the normalized load can be considered as a density function and the created load shapes are based on metered data on only few buildings, [NOR98] underlines the methods sensitivity regarding the origin buildings. Thus, the standard deviations are quit high [NOR98]. Nevertheless, the load profiles give a reasonable approximation as long as the occupation, such as school or hotel, building type and the mean value for the ambient temperature remains constant. [BOR01a] and [BOR01b] investigated various techniques to obtain demand profiles in order to create a framework to derive energy load profiles. Those profiles are subject of MERIT, a program to investigate supply and demand matching. [NOR01a] highlighted not only the importance of load profile in order to use them within a decision support tool, but also the applying methods to create those load profiles. Besides metered data, building simulation can be a very accurate means of deriving load profiles and is not limited to the existing building stock. However, the most significant disadvantage of this method is the specialist knowledge involved in creating accurate building models [NOR01a]. Thus, this contribution can be considered as very valuable in order to set up the method using scalable energy load profiles in the course of an urban simulation environment. [CLA13] has used the domestic hot water model described within [JOR01] and [JOR05] and the simulation program ESP-r to generate space and water heating profiles. Therefore, detailed simulations have been conducted for representative houses with regard to 34 combinations of building geometries, construction and heater configurations. [CLA13] outlines the importance of creating reference profiles for certain average outdoor temperatures in order to distinguish the patterns (magnitude and shape) of the demand profile. Due to [CLA13] has used the demand profiles to forecast the energy load profile by scaling up the most appropriate reference profile (1 out of 16.000) and the method within this thesis does not, the importance of varying average outside temperature does not apply to this thesis. However, [CLA13] has chosen a similar approach to scale up energy load profiles using pre-simulated reference profiles and thus, the results of [CLA13] have been very supportive in the preliminary stage of this thesis. Recent contributions of relevant scientific conferences underline the need towards urban energy planning tools or building modelling at an urban scale. For instance, [LI15] proposed an urban scale building energy modelling methodology that integrates geographical information with physical principle based simple energy calculation tool. Intended for large scale urban modelling instead of individual buildings, the methodology of [LI15] enables retrofit analysis and energy related policy development with regards to an annual basis. [SCH15] and [EIC15] underline the need of urban energy simulation methodologies in order to enable more interdisciplinary actions. Thus, [SCH15] focused on the impact onto the energy grids due to the load profile characteristics of different buildings (e.g. buildings age) within a neighborhood. [SCH15] also proposed to enable co-simulation considering buildings and energy grids. Except of the detailed methodology in order to generate electrical load profiles with respect to different occupation scenarios and the holistic and interdisciplinary approach of URBEM, this contribution has a similar approach to this thesis. [EIC15] has used an automated process to parameterize building simulation tolls using a building by building simulation process based on 3D CityGML geometry data. Thereby the focus was on the heating and cooling demand within building neighborhoods or communities in order to estimate heating and cooling demand as well as the potential of renewables. However, almost all mentioned contributions can be considered as early stage research projects and thus, make all methodologies towards urban simulation tools with respect to the requirements of decision support tools very important.

As the milieu based approach within this thesis is a significant input, a basic understanding regarding social differentiation is even more important. [HAU13] was among the first which has developed a method in order to highlight the impact of different milieus onto the electrical load profiles taking into account residential buildings. Thus, the contribution of [HAU13] has been used in order to set up the preliminary simulation model in order to make it as suitable as possible regarding the different input parameters coming along with a milieu bases approach.

As this thesis addresses a various scientific disciplines, the importance of a consistent energy balancing method becomes significant. [MUE15] addresses the issue of different energy wording terms related to different disciplines. According to [MUE15] energy economics usually relate their energy balancing to the EN15603:2008 [EN08]. Unlike the energy economics, civil engineers tend to use the energy balancing method given in [IEA13]. Therefore, chapter 3.1 addresses the missing link of those approaches and propose a consistent way for all further energy balancing measure within this thesis.

2.1 Considerable preliminary work

Due to all previous mentioned contributions are mainly related to one specific field of research, the upcoming sub chapter focuses on considerable preliminary work related to the interdisciplinary approach given in chapter 1.3.

2.1.1 Seestadt Aspern

On the example of the “Seestadt Aspern”, a new developed building neighborhood within Vienna, [HDZ12] addresses the challenge to create a simulation prototype taking into account the disciplines of building simulation as well as the simulation of thermal and electrical grids. The overall aim was to outline the potential of an optimal energy distribution with respect to the impact of renewable energy sources within that building neighborhood. Thus, a new developed simulation architecture has been established.

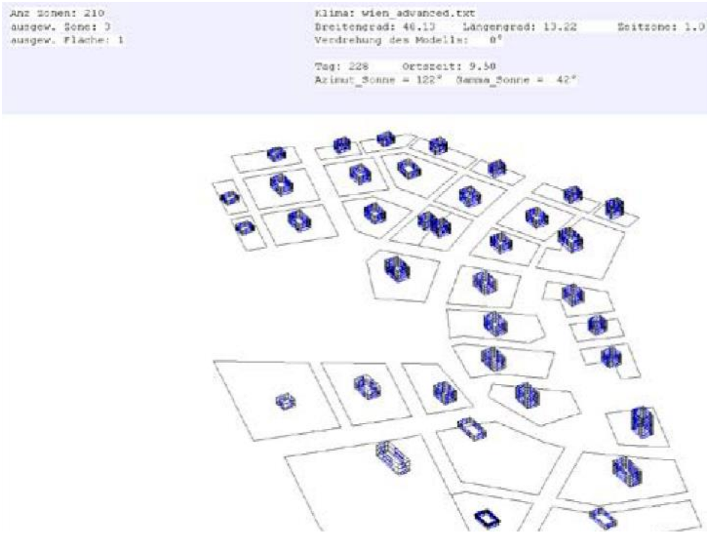

Figure 5: Screenshot of the Program BuildOpt_VIE. The figure illustrates the considered building neighborhood within that research.

As in [HDZ12] explained, a various of input parameters are necessary to run the building simulation model. However, according to Table 2 those input parameters are not available within this thesis. The results of the building simulation model for each building have been used as input data for the simulation model regarding the thermal and electrical grid. Therefore, all results are time and location sensitive. Due to the uncertainties concerning the individual load profiles of buildings, data from [BGW06] and [GHA11] have been used. Furthermore, due to this model has been set up as a prototype, the input and simulation efforts have been very time intense and the data link wasn't automated. Nevertheless, this project was among the firsts addressing interdisciplinary modeling with focus on a building neighborhood. Thus, this work highlights the significant challenges and further research efforts and makes this contribution highly valuable in order to go further.

2.1.2 City SIM

According to [CSIM16], the software CitySim is aiming to provide a decision support tool for urban energy planners and stakeholders and thus, makes that software a valuable preliminary work. Basically, CitySim uses 3D geometrical building forms at the scale of urban building neighborhoods to generate building models in order to use them to run a simulation engine. The approach is to focus on the heating, cooling and electricity demand of individual buildings using the ENERGYPLUS simulation engine. Within [KAM15], first results have been verified using the best test.

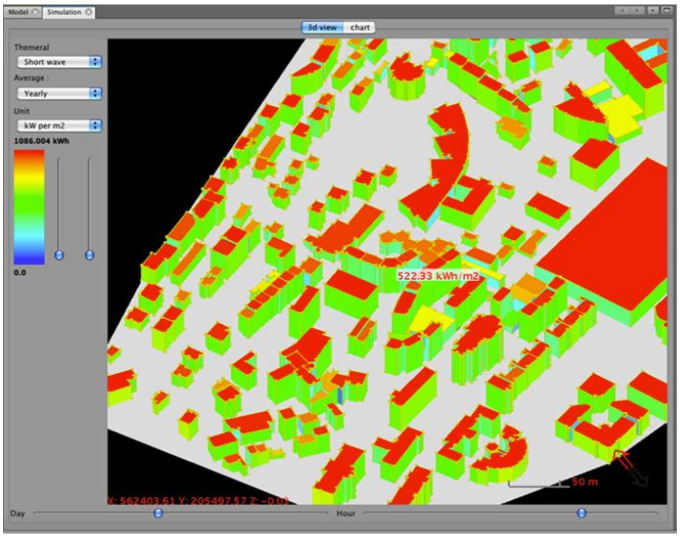

Figure 6: Screenshot of the CitySim software [CSIM16].

It is noticeable that the approach of CitySim is similar to the approach of [HDZ12] given in Figure 5, however, the software CitySim pays more attention towards an appropriate visualization in order to serve as a decision support tool. However, the project team of CitySim recently announced a comprehensive 3 years' project similar to the objectives of URBEM starting 2016. This fact even highlights the importance of the overall objectives within UBREM. Furthermore, [THO14] addresses the challenges and the need to enable co-simulation with interdisciplinary simulation tools. Thus, an early stage approach to couple the software CitySim with ENERGYPLUS using data derived from a building information model (BIM) using ©Autodesk Revit is given in [THO14].

2.1.3 CI-NERGY

The CI-NERGY project will provide a very high quality training network for urban energy management, where high profile universities and research centers cooperate with the industrial sector (both SME and large enterprises) to develop solutions for the smart cities of tomorrow. The overall aim of CI-NERGY is to develop a comprehensive methodology for the planning and operation of future energy systems of cities through the training and cultivation of ERs. The approach adopts a holistic vision that integrates energy efficiency measures together with energy services synergies, behavioral changes, innovative buildings design, advanced energy conversion technologies and advanced control strategies (http://www.ci-nergy.eu/Methodology.html - 29.08.2016). Unfortunately, recent publications in the field of buildings physic and energy load profiles are not available yet. However, this research project has a lot in common with the URBEM projects and thus, makes CI-NERGY highly valuable in order to compare with.

Figure 7: CI-NERGY visual downloaded at (http://www.ci-nergy.eu/Goals.html - 29.08.2016); Picture by Giorgio Agugiaro.

2.2 Conclusions regarding the state of the art

The current state of the art shows clearly, that individual models within all considered disciplines are well developed or even well disseminated. However, it is also noticeable that the interdisciplinary scope of each model is either not existing or limited. Recent projects such as [HDZ12] and [CitySim] show a tendency towards fundamental interdisciplinary work. But [HDZ12], [CSIM16] as well as [MUE15] also emphasize that interdisciplinary work does also come along with interdisciplinary challenges (e.g. energy terms within different scientific disciplines). However, current research efforts such as the comprehensive and holistic projects City SIM and CI-NERGY, which both have a similar research issue than the URBEM project, emphasize not only the need of accurate and validated urban decision support tools but also the importance of an interdisciplinary scientific setup.

3 Method

This chapter is focusing on the established methods within this thesis. Due to its interdisciplinary approach, this chapter addresses the applied methods regarding energy boundaries, building physics, HVAC design, sociological differentiation as well as the simulation setup.

3.1 Energy system boundaries and definitions

According to [MUL15], there are no or too little resilient definitions regarding the use of energy terms. Especially within interdisciplinary scientific disciplines such as energy economics and civil engineering. Due to the interdisciplinary framework within the URBEM, the definition of all used energy terms within this thesis becomes even more important. In order to balance all energy flows consistently, the work of [IEA13] represents the basis for all upcoming energy terms and balancing boundaries.

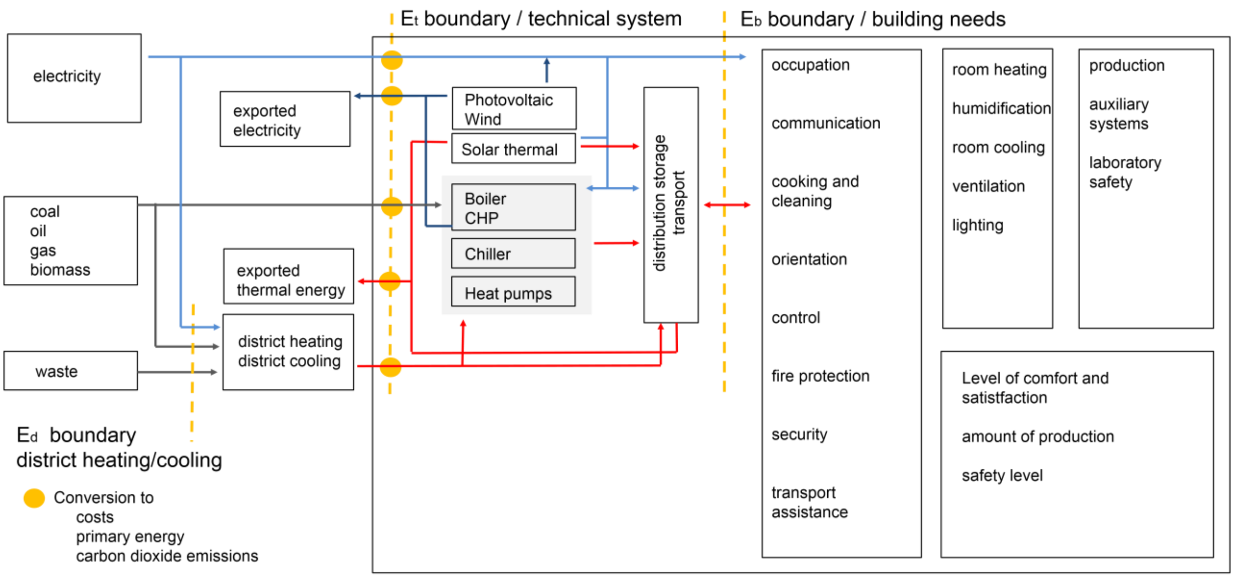

Figure 8: Detailed definition regarding the energy boundaries in order to distinguish energy terms consistently and accurately according to [IEA13] and [HDZ13].

Figure 8 emphasizes the 2 important energy boundaries E_b and E_t given in [IEA13] and extended in [HDZ13]. The energy boundary of E_b represents the energy demand, or according to EN 15603:2008 [EN08], the energy need. This is including only the energy needs for space heating, space cooling and for the domestic hot water. On the other hand, the energy boundary E_t represents the energy delivered to the building for all technical systems. This is including not only losses due to the distribution but also losses due to the conversion within the building. According to EN15603:2008 [EN08], the energy boundary E_t represents the term delivered energy. According to [MUE15] an additional energy term is very common, the final energy demand. All previous cited standards do not specify the term of the final energy demand, because it´s definition has been made by the European directive 2009/28/EC and thus, makes this term important to the energy economics. [MUE15] also addresses how to merge those energy terms in order to use them consistently.

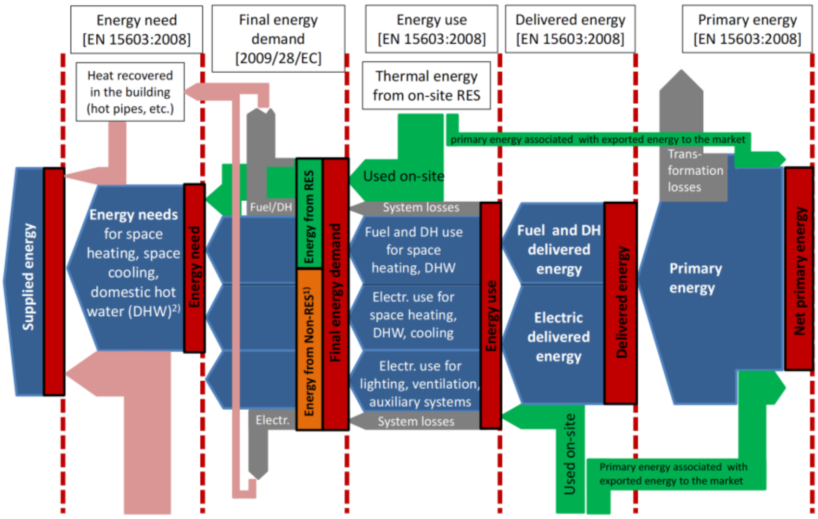

Figure 9: System boundaries for different energy terms according to [MUE15].

Based on Figure 9, the term of final energy demand can be found in between of the energy boundaries E_b (energy need) and E_t (delivered energy). Furthermore, the final energy demand deals with site specific parameters, such as the local climate or the real occupation [MUE15].

According to chapter 1.3 and Table 1 the input and output terms are indicated as FED – final energy demand and FEC – final energy consumption. To clarify all used energy terms including their energy balancing boundaries, a new method has been established in the course of this thesis given in Figure 10. In order to maintain an appropriate link, taking into account the EN15603:2008 [EN08], [IEA13] and [MUE15], this method can be considered as a resilient merging approach rather than a completely new developed definition method. Thus, this method merges energy terms of different interdisciplinary disciplines such as energy economics and civil engineering in a consistent way.

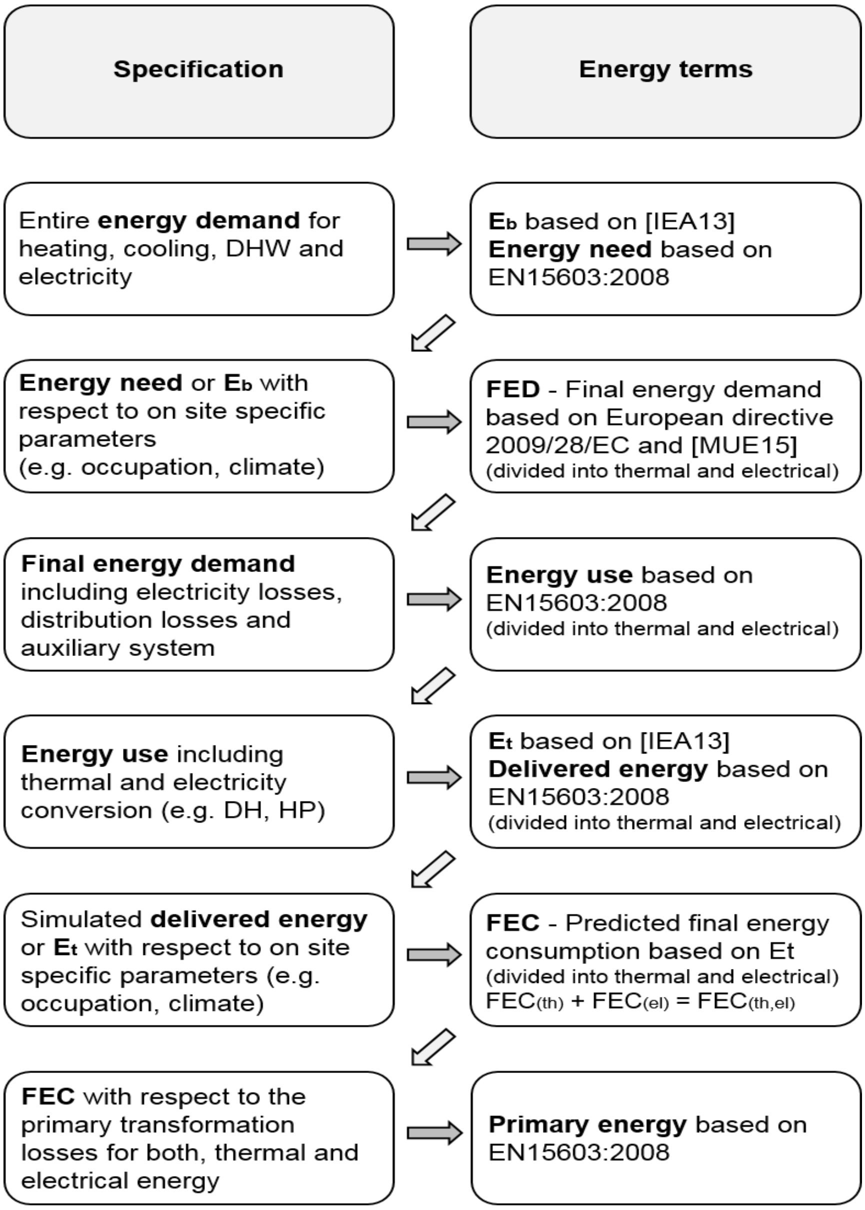

Figure 10: Clarification and definition of all applying energy terms within this thesis considering one building.

In conclusion, all energy terms within this thesis are related to the methodology given in Figure 10. Furthermore, due to the results within this thesis serve mainly as an input for the thermal and electrical grid (according to Table 1 and Figure 4), the predicted FEC - final energy consumption will always distinguish between thermal and electrical energy. Thus, this method enables a consistent way in order to provide thermal and electrical energy load profiles with respect to the overall objectives given in chapter 1.3.

3.2 Buildings

The sub chapter 3.2 gives an introduction regarding the method of creating density functions and outlines a detailed overview of the building cluster within this thesis and therefore, within the URBEM.

3.2.1 Density function

The method on how to create density functions for certain buildings has been described within the work of [ZIE15a] and [ZIE15c]. In order to enhance the readability within this thesis, the specifications of this method is given in the following.

Basically, the density function balances the heating and cooling demand at the level E_b with regards to [IEA13] according to Figure 10. In order to validate the results, the reference simulation has been conducted using BuildOpt_VIE. BuildOpt_VIE has been developed at the research center for Building Physics and Sound Protection at the TU Wien. It is a multi-zone model for hygrothermal calculations using up to 6000 thermal zones. Detailed specifications of BuildOpt_VIE are given in [WOL08]. Furthermore, BuildOpt_VIE has been validated with data from [IEA08], [KOR10] and [KOR11].

$$DF, Eb, heating, BC, i(t) = \frac{Q, Eb, heating, SIM, BC, i(t)}{\sum_{n=1}^{8760} Q, Eb, heating, SIM, BC, i} \qquad (1)$$

$DF_{Eb,heating,BC,i(t)}$	*Density function for each time step (t) related to a certain building (BC) and to a certain occupation (i) … [W/kWh]*
$Q_{Eb,heating,SIM,BC,i(t)}$	*Simulated heating load for each time step (t) related to a certain building (BC) and its occupation (i) … [W]*
$\Sigma\, Q_{Eb,heating,SIM,BC,i}$	*Simulated annual heating demand related to a certain building (BC) and its occupation (i) … [kWh]*

Equation (1) shows the formula to create a density function with respect to a certain building and its occupation. Therefore, the density function can be considered as a time sensitive share of the simulated heating load related to the simulated annual heating demand.

As the objective of this thesis deals with scalable energy load profiles, equation (2) shows the initialization of a certain density function using the scenario parameters given in Table 1.

$$Q, Eb, heating, BC, i(t) = DF, Eb, heating, BC, i(t) \times GFA, BC, i, A \times FED, th, BC, A \qquad (2)$$

$Q_{Eb,heating,BC,i(,t)}$	*Calculated heating load for each time step (t) related to a certain building (BC) and its occupation (i) with regards to E_b … [W]*
$GFA_{BC,i,A}$	*Gross floor area related to a certain building cluster (BC), occupation (i) and to the URBEM Scenarios (A) … [m^2]*
$FED_{th,BC,A}$	*Predicted final energy demand related to a certain building cluster (BC) and the UBREM Scenarios (A) with regards to either heating or cooling … [kWh/m^2yr]*

While [ZIE15a] focuses on the method and on the capabilities regarding the use of density functions, [ZIE15c] underlines its limits. According to equation (1), each density function is based on simulation results taking into account a certain building and its occupation and thus, makes each density function related to the specific characteristics of that certain building. In order to investigate the capability in terms of dealing with different building characteristics, [ZIE15c] has varied 3 parameters. The variable parameters deal with buildings of different sizes, different thermal qualities and different occupation scenarios. Based on the accuracy of the results, [ZIE15c] proposes to create specific density functions for each case. A key finding was that the building size and its compactness, its construction technology (e.g. thermal mass) as well as the occupation effects the thermal load profile characteristics the most. Thus, in order to classify buildings properly, the building matrix in terms of a building cluster has been established according to [MA11] and WP1 [FRI16] and is given within chapter 3.2.2. Regardless of the results of [ZIE15c], URBEM is taking into account all buildings given in [MA11]. Due to [MA11] distinguishes between buildings related to its size and age, the density functions have to distinguish between the building size and its age anyway. However, another key finding of [ZIE15c] addresses the great accuracy of density functions in the course of refurbishments. This is due the fact that the specific qualitative thermal load profile characteristics (e.g. due to building mass, size, occupation) remain constant. Thus, makes the density function capable to create scalable thermal load profiles with respect to scenario parameters such as the predicted specific annual heating demand.

3.2.2 Building stock of Vienna

According to the data of [BAU12], [OIB15] and several other studies, Table 3 presents typical building physics parameters related to the age of buildings. Due to WP1 [FRI16] uses the buildings cluster of [MA11] as a basis, Table 3 relates those parameters to a specific building age.

Table 3: Building cluster in terms of building age according to [MA11] related to building physics parameters according to [BAU12] and [OIB15].

BC	Building Age	U_{Wall}	$U_{Ceiling}$	U_{Floor}	U_{Win}	g_{Win}	Inf.	Floor height	Density (Wall)
			W/m²K			-	1/hr	m	kg/m²
1	1879 – 1918	1.55	1.3	1.25	2.5	0.67	1.5	4.5	960
2	1944	1.5-2	0.6	1.2	2.5	0.67	1.5	4.5	850
4	1960	1.3-1.75	1.3	1.1-1.95	2.5	0.67	1.5	4.2	740
5	1970	1.2	0.55	1.35	3	0.67	1.5	4	530
6	1980 – 1991	1.15	0.45	1.1	2.5	0.67	1.2	3.5	530
7	1994 – 2002	0.7	0.45	1.85	3	0.67	1	3	500
8	> 2002	0.35	0.2	0.4	1.2-1.4	0.5-0.55	0.9	3	500

The given relation in Table 3 indicates the first step in order to establish a resilient building cluster within the URBEM. Thus, all further coding's regarding the building cluster are using BC1 to BC8 and represents the buildings age. Additionally, all geometrical data regarding all building models are given in Table 35 within chapter 7.5.

Both, [BAU12] and [OIB15] address the significant impact onto the predicted final energy demand due to the surface / volume ratio considering E_b of [IEA13]. Thus, the energy demand regulations within [OIB15] are subject of the buildings surface / volume ratio, which is also well known as the compactness of buildings. Equation (3) points out that ratio in order to determine the compactness of a building.

$$A/V,BC = \frac{\sum_{i=1}^{n} A,BC}{\sum_{i=1}^{n} V,BC} \qquad (3)$$

A/V_{BC}	*Surface / volume ratio of a certain building … [m^2/m^3]*
ΣA_{BC}	*The sum of all buildings surfaces which are subject of heating losses … [m^2]*
ΣV_{BC}	*The sum of the buildings conditioned volume … [m^3]*

The following equations (4) and (5) are showing the minimal requirements according to the Austrian building regulation [OIB15] in the course of both, building refurbishment and new buildings. The required heating demand refers to the heating demand according to E_b of [IEA13].

$$Eb,BC = Z \times (1 + \frac{3}{lC,BC}) \qquad (4)$$

$$lC,BC = \frac{1}{A/V,BC} \qquad (5)$$

Eb_{BC}	*Required reference heating demand according to [OIB15] with respect to Eb of [IEA13] … [kWh/m^2yr]*
Z	*Offset, ranges from 14 to 23 and relates to either a new building or refurbished buildings [OIB15] … [-]*
$l_{C,BC}$	*Characterizing length of a building / inverse of the A/V,BC … [m]*

Table 4 is showing the context of the building size to its surface / volume ratio. It becomes clear that the smaller the buildings the higher the surface / volume ratio and on the other hand, the bigger the buildings the lower the surface / volume ratio. Detailed geometrical data (e.g. length, width, height) are given in Table 35 within chapter 7.

Table 4: Buildings sizes in accordance with work package 1 in order to address buildings with different surface / volume ratios (e.g. family house and multifamily houses).

BC	GFA m^2	Window/Wall ratio -	Surface/Volume ratio 1/m
1	GFA < 500	0.20-0.71	0.53-0.62
2	5.000 < GFA < 500	0.15-0.61	0.26-0.29
3	GFA > 5.000	0.15-0.51	0.21-0.24

According to the equations above, the higher the compactness of a building the higher the requirements onto the minimal heating demand. In order to address that fact, the established building cluster is taking into account also the buildings size. Thus, all further coding's regarding the building cluster, are using BCx-1 to BCx-3 and represents both the buildings age (x) and its size (1 to 3).

Table 5: Example naming for the building cluster in order to ensure a consitent coding procedure within the URBEM.

Example naming	Buildings age	Size
	-	m²
BC8-1	> 2002	GFA < 500
BC4-2	1960	500 < GFA < 5.000
BC1-3	1879 – 1918	GFA > 5.000

Table 5 represents a brief example regarding the naming of the applied building cluster within this thesis. In order to meet the scientific standards even in that interdisciplinary environment of URBEM, a consistent and clear coding is of great importance.

3.3 HVAC design

In order to balance at the level of E_t instead of E_b [IEA13], the modeling of certain HVAC designs becomes even more important. Thus, a wide setup of HVAC design opportunities has been implemented with respect to the needs of URBEM and the WStW. A brief matrix related to the HVAC design opportunities is given within Table 6.

Table 6: HVAC design opportunities within the simulation model with respect to the URBEM context.

Heating	DHW	Cooling	Distribution
District heating (DH)	District heating	Piston ($C1_{CC}$, $C2_{FC}$)	RH - Radiant heating 55°C
Gas	Gas	Screw ($C3_{CC}$, $C4_{FC}$)	FH - Floor heating 35°C
Heat pumps (HP1-HP6)	Heat pumps	Turbo ($C5_{CC}$, $C6_{FC}$)	FC - Fan Coil 12°C
electric	electric		CC - Cooling ceiling 18°C

The detailed specifications and the modeling algorithm of all implemented HVAC components are given within chapter 3.3.1 to 3.3.4. However, energy storages have not been considered yet and thus, the implementation of energy storages within this HVAC model are subject of future work.

3.3.1 Heating

As Vienna is taking advantage of a great district heating and gas grid almost all buildings are either connected to the district heating or to the gas grid. However, since heat pumps become more famous for both, heating and domestic hot water, URBEM focuses on heat pumps too. Not least to enhance the capabilities of the URBEM scenarios.

Table 7: Applying efficiency ratio regarding a district heating system, gas boiler, heat pumps as well as an electric system.

Heating ($\eta_{(k,t)}$)		Ratio
District heating	η_{DH}	0.95
Gas	η_{Gas}	0.98
Heat pumps	$\eta_{HP(t)}$ / $COP_{(t)}$	see equation (10)
Electric	η_{el}	0.95

In accordance with the WStW, the efficiency ratios for the district heating, gas and electric heating systems remain constant regardless of the air and supply temperature. Due to the WStW are not only the owner of the facilities district heating, gas and electrical grid, but also its operator, the efficiency ratios given in Table 7 can be considered as reliable as well as validated. However, the efficiency ratio for heat pumps correlates closely with the ambient and supply temperature – see equation (6). Thus, the procedure in order to establish a proper heat pump model is given in the following.

Table 8: Quality grade ratios for heat pumps related to the source air, ground and water, according to [BAU12].

Heat pump	Quality grade
Air / Water heat pump (HP-$A_{HP1,HP2}$)	$\varepsilon_{HP\text{-}A} = 0.34$
Ground / Water heat pump (HP-$G_{HP3,HP4}$)	$\varepsilon_{HP\text{-}G} = 0.45$
Water / Water heat pump (HP-$W_{HP5,HP6}$)	$\varepsilon_{HP\text{-}W} = 0.45$

Table 8 represents the quality grade ratios for different heat pumps regarding the heating source. Furthermore, the Carnot ratio describes the maximum theoretical efficiency ratio according to [SCH09] and is given in equation (6).

$$\zeta,C,HP(t) = \frac{\vartheta 1}{\vartheta 1 - \vartheta 0} \quad (6)$$

$\zeta_{C,HP}$	*Carnot ratio… [-]*
$\vartheta 1$	*Maximum temperature level of the heating system … [K]*
$\vartheta 0$	*Maximum temperature level of the ambient source (either air, ground or water) … [K]*

Due to the carnot ratio relates on the ambient source temperature levels, which are subject to change at every time step, all further calculations need to be done for every single time step. Due to losses within the evaporator and condenser [SCH09], equation (7) shows the final equations for the heat pump model in consideration of equation (8) and (9).

$$\zeta,C,HP(t) = \frac{\vartheta C(t)}{\vartheta C(t) - \vartheta E(t)} \quad (7)$$

$$\vartheta,C(t) = \vartheta 1(t) + \vartheta 1,C \quad (8)$$

$$\vartheta,E(t) = \vartheta 0(t) - \vartheta 0,E \quad (9)$$

$\zeta_{C,HP}$	*Carnot ratio… [-]*
ϑ_C	*Maximum temperature level of the heating system / Condensers temperature according to Table 6 … [K]*
ϑ_E	*Maximum temperature level of the ambient source (either air, ground or water temperature) / Evaporators temperature according to chapter 3.6.2 … [K]*
$\vartheta_{1,C}$	*Temperature offset taking into account condensers temperature losses according to [SCH09] … [K]*
$\vartheta_{1,E}$	*Temperature offset taking into account evaporators temperature losses according to [SCH09] … [K]*

On the basis of equation (6), equation (7) shows the real carnot ratio taking into account the temperature losses within the evaporator and condenser. In order to determine the heat pumps real efficiency ratios, also well known as the COP(t) – Coefficient of Performance - equation (10) specifies the variables. Additionally, equation (10) also considers losses due to the energy needs for the pumping [BAU12].

$$\eta, HP(t) = \zeta, C, HP(t) \times \epsilon, HP(k) \times (1 - \eta, aux, k) \quad (10)$$

η_{HP}	*Real heat pump efficiency ratio, also well known as the COP(t) – Coefficient of Performance… [-]*
ε_{HP}	*Quality grade ratio according to Table 8 … [-]*
$\eta_{aux,k}$	*Efficiency ratio due to auxiliary losses related only on the heat pumps system (0.15 – 0-18) according to [BAU12] … [-]*

Thus, the heat pump model considers not only the thermodynamic process of the heat pump itself, but also its auxiliary systems. The final coefficients of performance for each heat pump model are given in Figure 11.

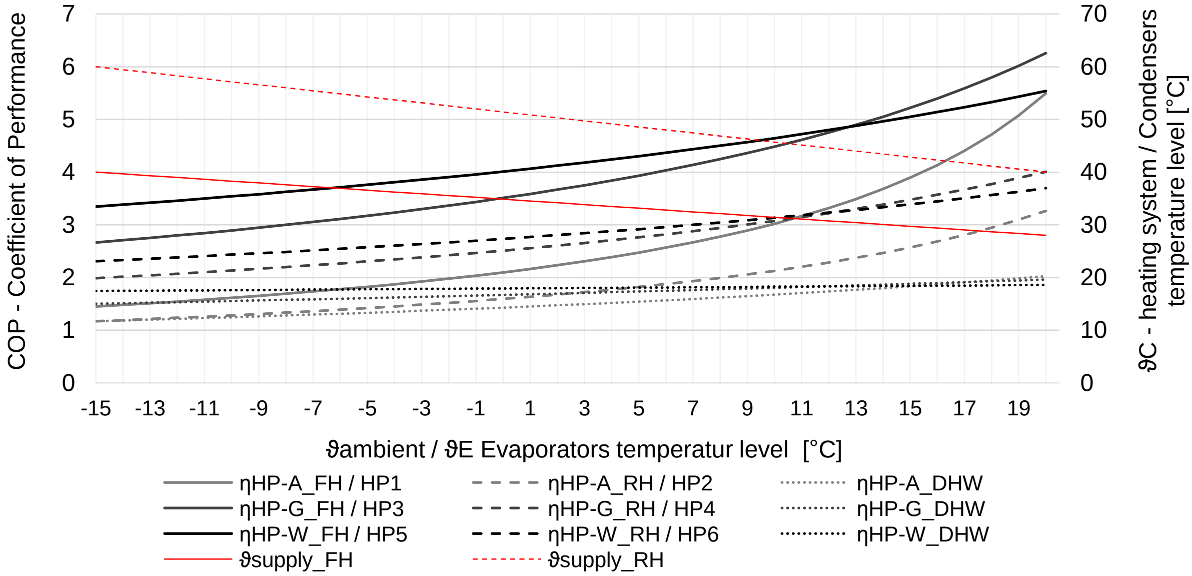

Figure 11: Results regarding the heat pumps COP, taking into account the ambient temperature as well as the heating supply temperature.

Due to balancing at the level of the final energy consumption (E_t), equation (11) shows the dependencies of the simulated heating load (E_b) and the HVAC's real efficiency ratio.

$$FEC, BC, i, k(t) = Q, Eb, heating, SIM, BC, i(t) \times \eta(k, t) \quad (11)$$

$FEC_{BC,i,k(t)}$	*Calculated final heating consumption related to a certain building (BC), its occupation (i) and to a certain HVAC design (k) with regards to E_t … [W]*
$Q_{Eb,heating,SIM,BC,i(t)}$	*Simulated heating load for each time step (t) related to a certain building (BC) and its occupation (i) with regards to E_b … [W]*
$\eta_{(k,t)}$	*Real energy efficiency ratio for the district heating, gas and electric according to Table 7 or for heat pumps according to equation (10) … [-]*

In terms of heating, equation (11) represents how to bridge the gap between balancing at the level of E_b and balancing at the level of E_t according to [IEA13]. Furthermore, this gap gets also addressed within Figure 51 as the decoupled HVAC model gets specified. As equation (1) indicates the general density function in the course of the validation procedure within chapter 3.2.1, equation (12) derives the final density function $DF_{heating,BC,i,k(t)}$ for each building (BC), occupation (i) and HVAC model (k) with respect to E_t of [IEA13].

$$DF,heating,BC,i,k(t) = \frac{Q,Eb,heating,SIM,BC,i(t)}{\sum_{n=1}^{8760} FEC,BC,i,k} \tag{12}$$

$DF_{heating,BC,i,k(t)}$	*Density function for each time step (t) related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to E_t ... [W/kWh]*
$Q_{Eb,heating,SIM,BC,i(t)}$	*Simulated heating load for each time step (t) related to a certain building (BC) and its occupation (i) with regards to E_b ... [W]*
$FEC_{BC,i,k}$	*Calculated final heating consumption related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to E_t ... [W]*

The final density function $DF_{heating,BC,i,k(t)}$ applies to the final equations (50) and (51) within chapter 3.6.4. in order to generate the scalable load profile.

3.3.2 Cooling

Analogues to chapter 3.3.1, this chapter addresses the HVAC modeling for the cooling. As Table 6 already indicated, 3 different cooling technologies have been taken into account within this thesis. As chillers are subject of the same thermodynamic cycle as heat pumps, the carnot ratio for chillers can be written as the following.

$$\zeta,C,CH(t) = \frac{\vartheta 0}{\vartheta 1 - \vartheta 0} \tag{13}$$

$\zeta_{C,CH}$	*Carnot ratio... [-]*
$\vartheta 1$	*Temperature level of the ambient source ... [K]*
$\vartheta 0$	*Temperature level of the cooling system ... [K]*

Due to the lack of data regarding validated quality ratios for chillers, several fact sheets have been investigated in order to determine typical quality ratios. In order to do so, equation (14) [SCH09] shows that the quality ratio is a function of the chillers energy efficiency ratio (EN14511) and its carnot ratio with regard to the eurovent conditions (ϑ_0=7°C/ ϑ_1=35°C).

$$\epsilon,CH(k,t) = \frac{Qth}{Pel} \times \frac{\vartheta 1 - \vartheta 0}{\vartheta 0} \tag{14}$$

ε_{CH}	*Quality ratio... [-]*
Q_{th}	*Thermal cooling capacity according to the eurovent conditions ... [W]*
P_{el}	*Electrical load according to the eurovent conditions ... [W]*

The calculated quality ratios are given in Table 9. The quality ratios for chillers are related on specific construction details, however, the given range within Table 9 can be also observed in [SCH09].

Table 9: Quality grade ratios for chillers related to the technology according to equation (14) with regards to the eurovent conditions (ϑ_0=7°C/ ϑ_1=35°C).

Chillers	Quality grade
Piston compressor (CH-P$_{C1,C2}$)	ε_{HP-A} = 0.4
Screw compressor (CH-S$_{C3-C4}$)	ε_{HP-G} = 0.45
Turbo compressor (CH-T$_{C5,C6}$)	ε_{HP-W} = 0.65

The above given calculated quality grades are sufficiently accurate in the course of the first HVAC design setup within this thesis. As the procedure is the same as given in equation (10) with respect to heat pumps, the real chiller energy efficiency ratio is given in the following.

$$\eta,CH,k(t) = \zeta,C,CH(t) \times \epsilon,CH,k \times (1-\eta,aux,k) \qquad (15)$$

$\eta_{CH,k(t)}$	*Real chiller efficiency ratio, also well known as the EER(t) – Energy Efficiency Ratio … [-]*
$\varepsilon_{CH,k}$	*Quality grade ratio according to Table 9… [-]*
$\eta_{aux,k}$	*Efficiency ratio due to auxiliary losses related only to the chillers system according to [BAU12] … [-]*

Analogues to Figure 11, the final energy efficiency ratios for each chiller model are given in Figure 12.

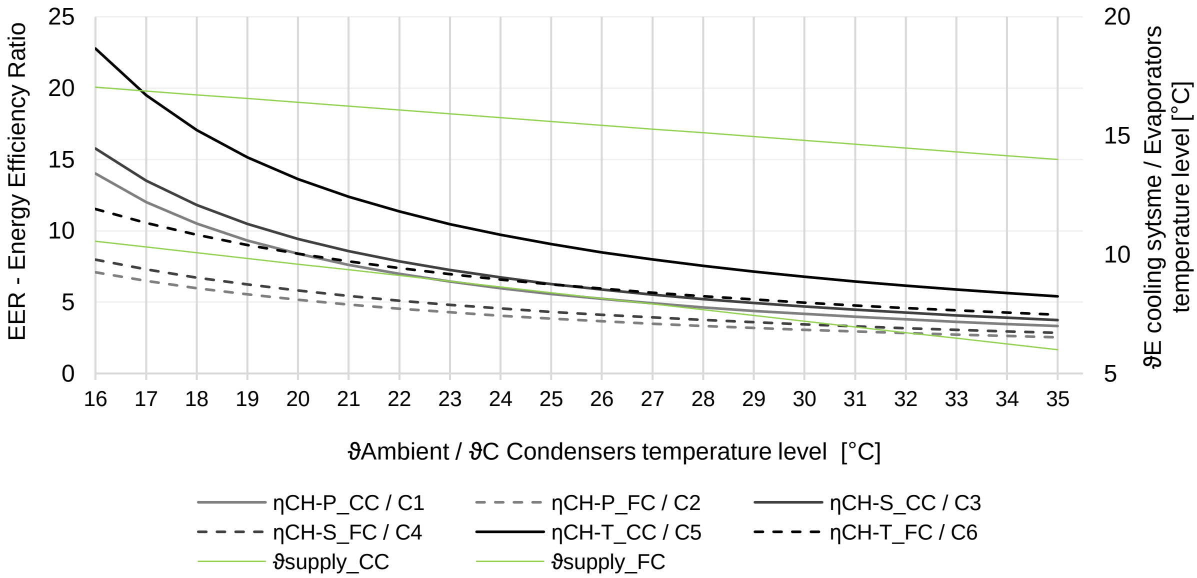

Figure 12: Results regarding the chillers EER, taking into account the ambient temperature as well as the cooling supply temperature.

Due to balancing at the level of the final energy consumption, equation (16) shows the dependencies of the simulated cooling load and the chillers real efficiency.

$$FEC,BC,i,k(t) = Q,Eb,cooling,SIM,BC,i(t) \times \eta(k,t) \times n,cool,i(t) \quad (16)$$

$FEC_{BC,i,k(t)}$	*Calculated final energy consumption related to a certain building (BC), its occupation (i) and to a certain HVAC design (k) with regards to* E_t *… [W]*
$Q_{Eb,cooling,SIM,BC,i(t)}$	*Simulated cooling load for each time step (t) related to a certain building (BC) and its occupation (i) with regards to* E_b *… [W]*
$\eta_{(k,t)}$	*Real energy efficiency ratio for all chillers according to equation (14) … [-]*
$n_{cool,i(t)}$	*According to Table 23 within chapter 3.4.5 … [%]*

Analogues to equation (12), equation (17) derives the final density function $DF_{cooling,BC,i,k(t)}$ for each building (BC), occupation (i) and HVAC model (k) with respect to E_t of [IEA13].

$$DF,cooling,BC,i,k(t) = \frac{Q,Eb,cooling,SIM,BC,i(t)}{\sum_{n=1}^{8760} FEC,BC,i,k} \quad (17)$$

$DF_{cooling,BC,i,k(t)}$	*Density function for each time step (t) related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to* E_t *… [W/kWh]*
$Q_{Eb,cooling,SIM,BC,i,(t)}$	*Simulated cooling load for each time step (t) related to a certain building (BC) and its occupation (i) with regards to* E_b *… [W]*
$FEC_{BC,i,k}$	*Calculated final energy consumption related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to* E_t *… [W]*

The final density function $DF_{cooling,BC,i,k(t)}$ applies to the final equation (51) within chapter 3.6.4. in order to generate the scalable load profile.

3.3.3 Domestic hot water

In order to model the specific DHW behavior for each milieu, the DHW model described in [JOR01] and [JOR05] has been used. The DHW_Calc program generates DHW profiles using a probability function and has been developed in the course of the IEA-SHC Task 26 on solar combisystems [JOR05]. The program has to be fed by flow rates, mean daily draw off, draw off periods, etc. Thus, makes the DHW_Calc suitable in order to use data from the questionnaires given in chapter 3.4.3. Basically, the program distinguishes between 4 sub categories.

Table 10: Input parameters for DHW_Calc [JOR01] and [JOR05] in order to generate milieu based DHW profiles in accordance with chapter 3.4.3.

Specification	Cat1[3] Short load (e.g. washing hands)	Cat2[3] Medium load (e.g. cooking)	Cat3 Bath	Cat4 Shower
Flow rate [l/min]	1	6	14	8
Mean draw off [liter/Per.day][1]	1	6	140	40
Applying mean draw off [liter/Per.day][2]	1	2	120	50

[1] … Assumptions of [JOR05], [2] … applying assumptions within this thesis in the course of a comprehensive top down calibration with data from [BAU12], [MAS14], [NEU15], [EST08], [3] … not a subject of the questionnaires, thus the default values have been used.

In accordance with the results given in chapter 3.4.3, only the categories 3 and 4 are subject of the milieu based questionnaires. Thus, the raw data of Figure 36 has been used to determine the mean values for the daily draw off with respect to each milieu.

Table 11: Final input data for the DHW_Calc based on the milieu based data of [HAU16b] given within chapter 3.4.1 (Milieu based attendances), 3.4.3 (Milieu based domestic hot water, number of draw offs for category 3 and 4) as well as Table 10 (draw off rates) with respect to the mean value of the gross floor area (GFA) of each milieu.

	MIL1	MIL2	MIL3	MIL4	MIL5	MIL6	MIL7	MIL8	MIL9	MIL10
GFA [m²]	94.92	74.47	92.7	86.65	90.4	84.7	85.05	83.83	77.67	73.73
Mean draw off [liter/day]	104	10	118	111	116	139	114	125	111	112
Cat1&2 [liter/day]	6	6	6	6	7	8	7	8	6	7
Cat3 [liter/day]	22	22	20	22	13	21	13	19	22	18
Cat4 [liter/day]	72	68	89	79	94	106	92	95	79	84
5:00-9:30	43%	44%	42%	36%	41%	40%	42%	41%	40%	37%
9:30-11:30	5%									
11:30-13:30	18%	17%	17%	20%	20%	18%	19%	19%	20%	21%
13:30-18:00	5%									
18:00-22:00	29%	28%	31%	33%	30%	32%	30%	30%	30%	33%

The milieu based daily probability given in Table 11 is based on the milieu based attendance given within chapter 3.4.1 and the default values of [JOR01] given in Figure 13.

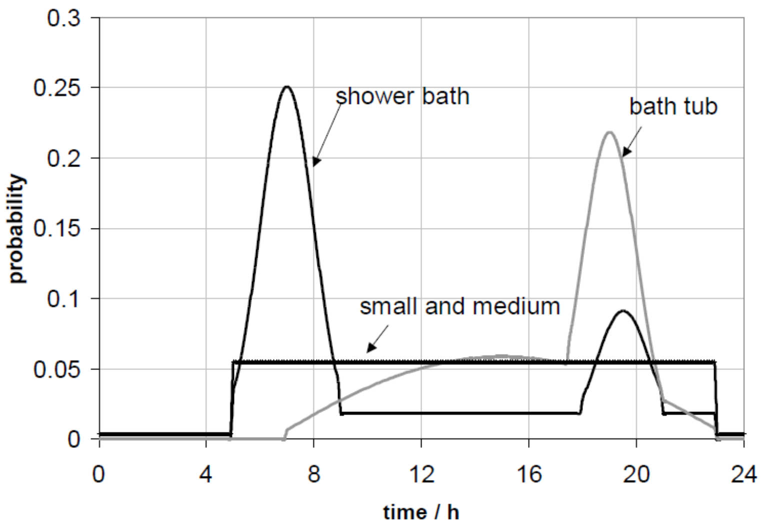

Figure 13: Probability distribution regarding the DHW load in the course of [JOR01]. Cat1 and Cat2 (small and medium) is distributed equally between 5:00 and 22:00 with 5% (see Table 11).

In order to create milieu sensitive DHW demand profiles, DHW_Calc uses the input parameters given within Table 11 and the probability function of [JOR01] given in Figure 13. Thus, example results for milieu sensitive DHW demand characteristics are given in the following.

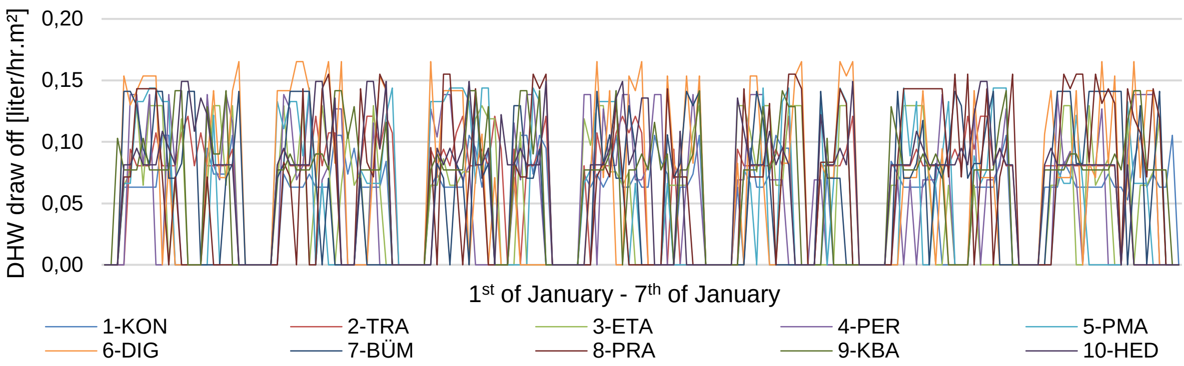

Figure 14: Probability distribution based on the DHW demand for each milieu with respect to E_b of [IEA13]. Due to the probability distribution of [JOR01], each day shows its own characteristics. However, the daily draw off rates remains constant and are based on Table 11.

Figure 14 shows the DHW demand characteristics, however, the results are subject of E_b and thus, do not consider any technical restrictions (e.g. system losses or losses due to the circulation pipe). In order to balance at the level of E_t, the results given in Figure 14 have been used as input parameters for the decoupled HVAC model which gets specified in the following.

Table 12: DHW temperature levels related to the building size and thus, to the losses due to the circulation pipes temperature level.

Building Size	Circ. Pipe	ϑ_{DHW} °C	ϑ_{Cir} °C	ϑ_{supply} °C
1	No	45	45	12
2	Yes	45	60	12
3	Yes	45	60	12

Due to hygienic reasons, the entire DHW system within bigger buildings has to maintain a temperature level of ϑ_{Cir}=60°C. Due to heat losses through the piping, the water has to circulate using circulation pipes in order to maintain ϑ_{Cir}. However, due to security reasons the temperature level at the draw off must not exceed ϑ_{DHW}=45°C. The circulation pipes are used parallel to the main DHW distribution (see $l_{Dis,BC}$ within equation (18) and (19)), while the length of draw off pipes (e.g. the final distribution within a dwelling) are not affected by the circulation (see $l_{Dis2,BC}$ within equation (20)). Based on that, the heating losses due to the circulation and distribution pipes are related to ϑ_{Cir} and ϑ_{t1_zone} (see equation (21)), while the predicted thermal energy consumption due to the DHW demand is related to the temperature ϑ_{DHW} and ϑ_{supply} (see equation (22)). In order to determine the system losses, all relevant parameters related to the buildings age according to [BAU12] are given in the following.

Table 13: System parameters related to the buildings age in order to determine the entire system losses [BAU12].

Buildings Age	$f_{ero,dis}$ [1]	fero,dis2 [2]	q_{pip} [3]	$q_{pip,l}$ [4]
	-	-	W/m²	W/m²
1	1.7	1.35	0.45	2.42
2	1.55	1.275	0.4	2.42
4	1.4	1.2	0.35	1.08
5	1.325	1.165	0.3	1.08
6	1.25	1.13	0.28	1.08
7	1.225	1.115	0.26	1
8	1.2	1.1	0.24	1

[1] … thermal insulation parameter for valves, pumps, etc. related to the main distribution pipes
[2] … thermal insulation parameter for valves, pumps, etc. related to the final distribution pipes
[3] … heat losses related to the ratio thickness of the thermal insulation to the diameter of the pipes
[4] … heat losses due to the material of the pipes (Steel, cooper and plastic pipes)

As the system parameters of [BAU12] given in Table 13 are not directly related to a certain building age, values in between have been linear interpolated with respect to the given maximum and minimum of [BAU12]. Thus, older buildings (e.g. BC1) are subject of higher heating losses due to piping and are equipped with steel pipes, while newer buildings (e.g. BC8) assume more thermal insulation and plastic pipes. In the following, equation (18) to (23) show the time sensitive heating load due to the entire DHW system.

$$l,dis,BC1 = (7 + 0.013 \times GFA,BC) + 0.05 \times GFA,BC \quad (18)$$

$$l,dis,BC2,3 = (13 + 0.013 \times GFA,BC) + 2 \times 0.05 \times GFA,BC \quad (19)$$

$$l,dis2,BC = 0.2 \times GFA,BC \quad (20)$$

$$\begin{aligned} Q,Eb,DHW,losses,BC(t) &= (f,ero,dis \times q,pip + q,pip,l) \times l,dis,BC \times (\vartheta,Cir - \vartheta z1,tair,i(t)) \\ &+ (f,ero,dis2 \times q,pip + q,pip,l) \times l,dis2,BC \times (\vartheta,Cir - \vartheta z1,tair,i(t)) \end{aligned} \quad (21)$$

$$Q,Eb,DHW,demand,i(t) = m,i(t) \times (\vartheta,DWH - \vartheta,supply) \times c,water \times GFA,BC \quad (22)$$

$$Q,Eb,DHW,BC,i(t) = Q,Eb,DHW,losses,BC(t) + Q,Eb,DHW,demand,i(t) \quad (23)$$

$l_{dis,BC1}$	*Piping length for the main distribution without a circulation system and thus, only related to building size 1 according to [BAU12] ... [m]*
$l_{dis,BC2,3}$	*Piping length for the main distribution with a circulation system and thus, only related to building size 2 and 3 according to [BAU12]... [m]*
$l_{dis2,BC2,3}$	*Piping length for the final distribution according to [BAU12]... [m]*
$Q_{Eb,DHW,losses,BC(t)}$	*Heating loads due to system losses according to [BAU12] ... [W]*
$Q_{Eb,DHW,demand,i(t)}$	*Heating loads due to the milieu based DHW demand ... [W]*
$Q_{Eb,DHW,BC,i,(t)}$	*Time sensitive heating loads due to the entire DHW system including the DHW demand and system losses ... [W]*
$\vartheta_{z1,tair,i(t)}$	*Temperature level of the thermal zone for each milieu according to chapter 3.4.5 ... [°C]*
$m_{i(t)}$	*Milieu based DHW demand according to Table 11 and Figure 14 ... [kg/hr.m²]*
c_{Water}	*Specific heating capacity of water ... [Wh/kgK]*

Analogues to chapter 3.3.1, $Q_{Eb,DHW,BC,i(t)}$ does not included the system losses due to the heating system. Thus, equation (24) shows the balancing towards the level of E_t [IEA13].

$$FEC,DHW,BC,i,k(t) = Q,Eb,DHW,BC,i,k(t) \times \eta(k,t) \qquad (24)$$

$FEC_{DHW,BC,i,k(t)}$	*Final thermal/electrical energy consumption for the DHW in order to generate the scalable energy load profile according to chapter 3.6.4 with regard to E_t ... [W]*
$\eta_{(k,t)}$	*Real energy efficiency ratio for the district heating, gas and electric according to Table 7 or for heat pumps according to equation (10) ... [-]*

Finally, equation (25) derives the DHW density function $DF_{DHW,BC,i,k(t)}$ for each building (BC), its occupation (i) and HVAC model (k) with respect to E_t of [IEA13].

$$DF,DHW,BC,i,k(t) = \frac{FEC,DHW,BC,i,k(t)}{GFA,BC} \qquad (25)$$

$DF_{DHW,BC,i,k(t)}$	*Density function for each time step (t) related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to E_t ... [W/m²]*

The final density function $DF_{DHW,BC,i,k(t)}$ applies to the final equation (50) and (51) within chapter 3.6.4. in order to generate the scalable load profile.

3.3.4 Ventilation

Mechanical ventilation systems become very famous especially for new office buildings. In the course of this thesis a simple model regarding the mechanical ventilation system has been used only in the course of new office buildings. Therefore, the heat exchange ratio has been set to 75%. However, a more detailed implementation of mechanical ventilation systems will be a subject of further research.

$$Pel,mv(t) = V,BC \times SFP \times n,mv(t) \times \frac{1}{\eta,el} \qquad (26)$$

$P_{el,mv(t)}$	*Electrical load due to the mechanical ventilation system for each time step related to the real office occupancy ... [W]*
V_{BC}	*Buildings net volume ... [m³]*
SFP	*Specific fan power of the mechanical ventilation system (SFP=0.45) with regards to SPF4 of [EN07] ... [Wh/m³]*
$n_{mv(t)}$	*Air exchange rate for office buildings. $n_{mv,7:00-19:00}=1$; $n_{mv,19:00-7:00}=0$ ... [1/hr]*
η_{el}	*Electrical efficiency ratio according to Table 7 ... [-]*

As given in equation (26), the buildings mechanical ventilation system is only operating during 7:00 and 19:00.

3.3.5 Auxiliary system

The auxiliary system specifies the electrical energy needs due to pumping, controlling, etc. Thus, the energy needs for the auxiliary system correlates with the time sensitive final energy consumption. The auxiliary energy needs have been assumed as constant ratios and are given within equation (27).

$$Pel, aux(t) = (Q, Eb, heating, BC, i(t) + Q, Eb, DHW, BC, i(t)) \times \eta, aux, heating + Q, Eb, cooling, BC, i(t) \times \eta, aux, cooling \quad (27)$$

$P_{el,aux(t)}$	*Electrical load due to the auxiliary energy needs related to the heating, DHW and cooling system ... [W]*
$Q_{Eb,heating,BC,i(t)}$	*Calculated heating load for each time step (t) related to a certain building (BC) and its occupation (i) according to equation (11) ... [W]*
$Q_{Eb,DHW,BC,i(t)}$	*Calculated DHW load for each time step (t) related to a certain building (BC) and its occupation (i) according to equation (23) ... [W]*
$Q_{Eb,cooling,BC,i(t)}$	*Calculated cooling load for each time step (t) related to a certain building (BC) and its occupation (i) according to equation (16) ... [W]*
$\eta_{aux,heating}$	*Electrical efficiency ratio for the heating auxiliary system $\eta_{aux,heating}$=0.01 ... [-]*
$\eta_{aux,cooling}$	*Electrical efficiency ratio for the cooling auxiliary system $\eta_{aux,cooling}$=0.05 ... [-]*

Equation (28) derives the density function $DF_{aux,BC,i,k(t)}$ related to the auxiliary energy needs for each building (BC), its occupation (i) and HVAC model (k) with respect to E_t of [IEA13].

$$DF, aux, BC, i, k(t) = \frac{(P, el, mv(t) + Pel, aux(t)) \times \frac{1}{\eta, el}}{GFA, BC} \quad (28)$$

$DF_{aux,BC,i,k(t)}$	*Density function for each time step (t) related to a certain building (BC), its occupation (i) and HVAC design (k) with regards to E_t ... [W/m²]*

The final density function $DF_{aux,BC,i,k(t)}$ applies to the final equation (50) and (51) within chapter 3.6.4. in order to generate the scalable load profile.

3.4 Occupation

This chapter focuses on the method on how to consider and implement a milieu based approach in order to create time sensitive electrical load profiles. Since this thesis is subject of an interdisciplinary approach, social differentiation within residential buildings becomes even more important. Thus, a comprehensive questionnaires coming from [HAU16b], delivers n=977 answers regarding the attendances, energy behavior, use of appliances as well as cooling and ventilation behavior. Therefore, a newly developed method on how to derive specific parameters coming from a sociological questionnaire into a suitable data set is given within the following chapters. Furthermore, each chapter describes the raw data and the method towards a milieu based input data set for the simulation engine. According to [HAU16b] the milieus are clustered to 10 groups (e.g. MIL1, MIL4 or MIL10).

Since all answers coming from [HAU16b] are clustered to 10 milieus all further results are clustered the same way. Thus, the following method focuses on the mean values for each milieu, but not on results based on individuals. However, some significant differences regarding the maximums and minimums due to individual data with the calculated mean values are highlighted. The number of answers in terms of raw data coming from the questionnaires of [HAU16b] are given in Figure 15.

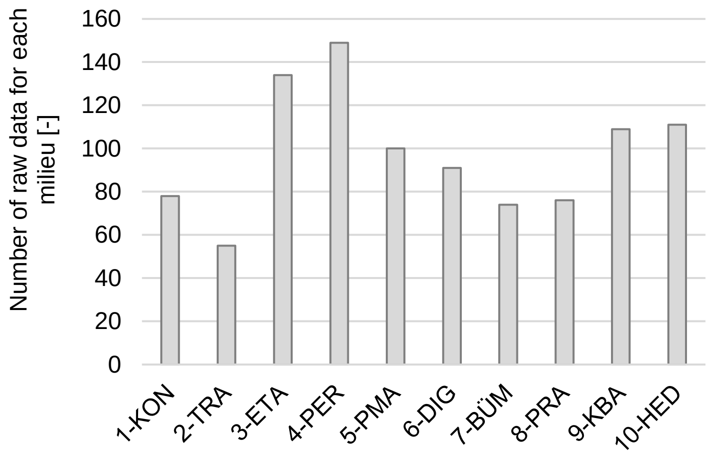

Figure 15: Number of answers in terms of raw data coming from the questionnaires of [HAU16b] for each milieu, by n=977.

3.4.1 Milieu based attendances

The basic raw data regarding general information and the attendances coming from [HAU16b] are given in the following.

Table 14: Basic information according to the questionnaires [HAU16b] regarding the dwellings size [m²], Persons per household and the attendances related to a week day and weekend day.

	GFA m²	Persons/Household -	Attendance WD -	Attendance WE -
∑ n (n=977)	$GFA_{(i)}$	nPer,i(t)	nAtt,i(t)	nAtt,i(t)

While the $GFA_{(i)}$ and $n_{Per,i(t)}$ are specific parameters which are easy to deal with, the answers regarding the attendances are not. Thus, Table 15 shows the applying time cluster in the course of the questionnaires.

Table 15: Time cluster within the questionnaires with regard to a week day (WD) and weekend day (WE).

WD	22-6	6-12	12-15	15-18	18-22	22-6
WE	22-6	6-22				22-6

As can be seen in Table 15 there are 4 time cluster regarding the day attendances and 1 for the night attendances, when considering a week day. However, there is only a single time slot for the day and night, when considering a weekend day. Due to each answer for each time slot is either yes (at home) or no (not at home), the time profile for each milieu can be easily derived and is given in the following.

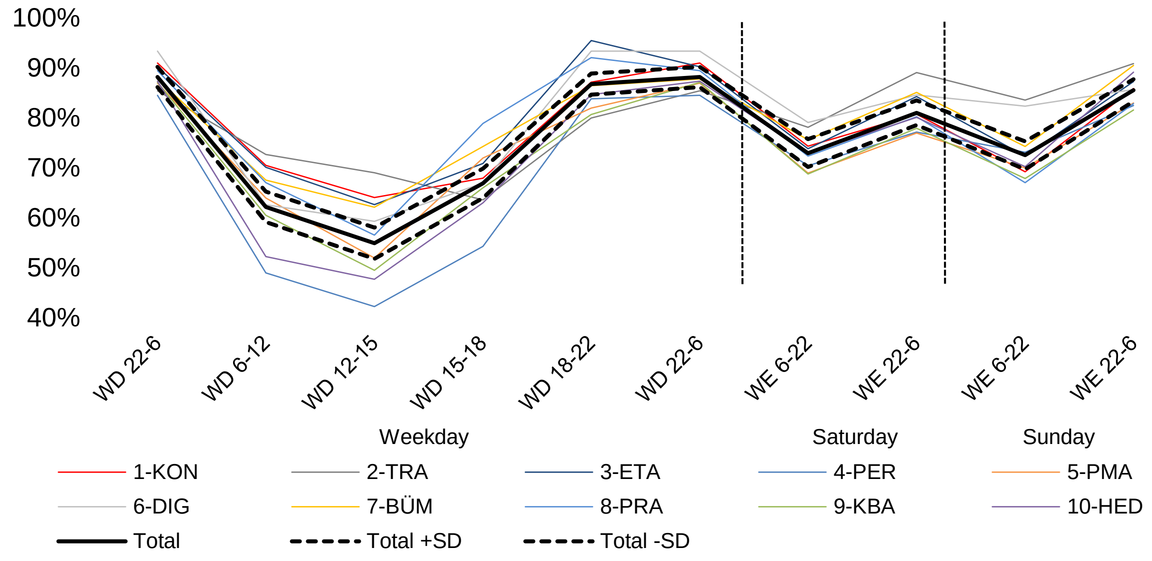

Figure 16: Deviation of the mean value for the general attendances $n_{Att,i(t)}$ considering all milieus, related to the overall mean value including the standard deviation $n_{Att(t)}$. The given attendances are based on the raw data from [HAU16b].

Figure 16 shows clearly that the general attendances for each milieu $n_{Att,i(t)}$ exceeds extremely often the bandwidth of the overall mean value $n_{Att(t)}$ including the standard deviation. Additionally, Figure 16 gives an idea of the attendance behavior for each milieu. During the evening hours almost 90% are at home, during working hours only 55%. Correlating to the attendances, the smaller the number for the attendances, the bigger the bandwidths for the standard deviation. It is also considerable that the attendances within all milieu is significantly higher during the weekend. Therefore, Figure 17 and Figure 18 emphasizes that impact at the level of a week day and weekend day.

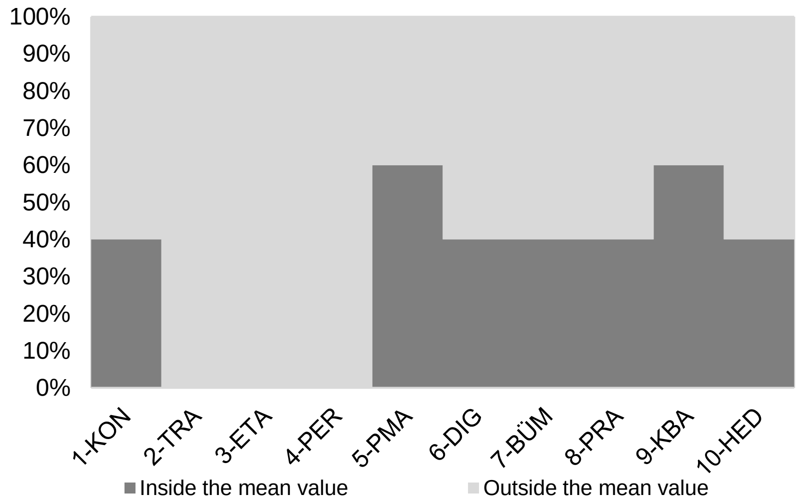

Figure 17: Correlation regarding the deviation for the specific attendances of each milieu and the overall mean value including the standard deviation, considering a week day. At 68% of the week day, with regard to the time cluster of Table 15, the specific attendances for each milieus are not within the given bandwidth of the overall mean value including the standard deviation $n_{Att(t)}$ given Figure 16. Furthermore, milieu 2, milieu 3 and milieu 4 has no match at all.

Figure 17 illustrates the importance of a milieu oriented approach. Within a week day, only 32% of the specific attendances for all milieus are within the bandwidth of the overall mean value including the standard deviation. Moreover, 3 out of 10 milieus have no match at all with the given bandwidth in Figure 16. Analogues to Figure 17, the results regarding the deviation of the specific attendances considering a weekend day are given in Figure 18.

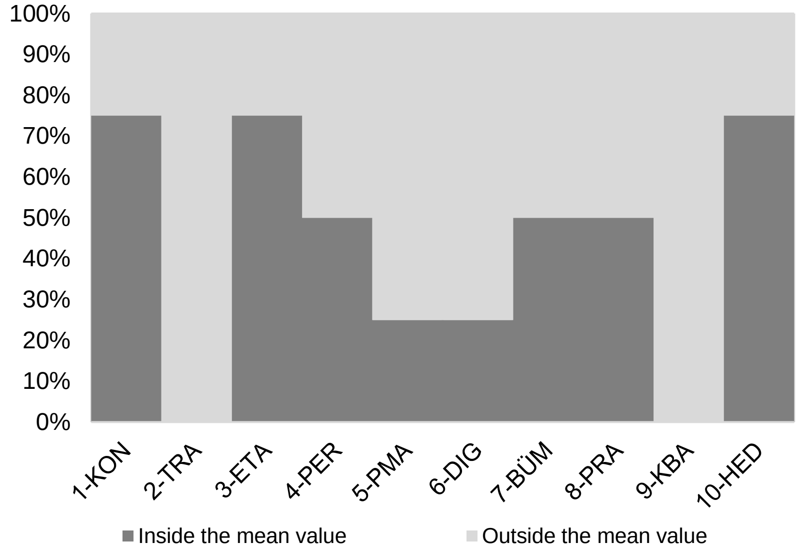

Figure 18: Correlation regarding the deviation for the specific attendances of each milieu and the overall mean value including the standard deviation, considering a weekend day. At 57.5% of the weekend day, with regard to the time cluster of Table 15, the specific attendances for each milieus are not within the bandwidth of the overall mean value including the standard deviation $n_{Att(t)}$ given Figure 16. Furthermore, milieu 2 and milieu 9 has no match at all.

Analogues to the week day, the same findings can be observed for the weekend day. 42% of the specific attendances for all milieus are within the bandwidth for the overall mean value including the standard deviation. Moreover, 2 out of 10 milieus have no match at all with the given bandwidth in Figure 16. A comprehensive understanding regarding the attendances effects the understanding of the occupation behavior significantly and thus, it influences all further calculations and assumption regarding the energy consumption with focus on time sensitive load profiles. The results show clearly that a simple mean value doesn't generally meet the real attendances for all milieus. Without that understanding differences regarding the time of use for electrical appliances, draw off behavior for domestic hot water, etc., can't be addressed sufficiently. Therefore, the results of chapter 3.4.1 influence all further actions within that thesis significantly.

3.4.2 Milieu based electrical appliances

As the attendance for milieus is well known, another part of the questionnaires focuses on the electrical appliances. Thus, not only the amount and type of electronic appliances has been asked, but also the duration and time of use with regard to the time cluster given in Table 15. The answers have been given as numbers, e.g. 2 televisions or 1 dishwasher per household.

Unfortunately, some answer obviously exceeds realistic behavior (e.g. 20 notebooks) and thus, a simple algorithm has been used in order to over write those answers instead of deleting the entire data set [HAU16a].

$$n, App, max, i, m = n, Per, i + a, App, m \quad (29)$$

$$n, App, i, m < n, App, max, i, m = n, App, i, m \quad (30)$$

$$n, App, i, m > n, App, max, i, m = n, App, MVi, m \pm SD, i, m \quad (31)$$

$n_{App,i,m}$	*Calculated or given number for each electronic appliance related to each milieu (i) ... [-]*
$n_{App,max,i,m}$	*Maximum number for each appliance (m) related to the offset and to the persons per household for each milieu (i) ... [-]*
$n_{App,MVi,m}$	*Mean value of the number for each electronic appliance related to each milieu (i) ... [-]*
$n_{Per,i}$	*Persons per household for each milieu (i) ... [-]*
$a_{App,m}$	*Offset for each electronic appliance (m) ... [-]*
$SD_{i,m}$	*Standard deviation for that specific electronic appliance related to each milieu ... [-]*

In order to calculate $n_{App,max,i,m}$, the offset value $a_{App,m}$ is given within Table 16.

Table 16: Offset values for each electronic appliance in order to determine the maximum number of appliances according to equation (28).

	Notebook	TV	Entertainment	Oven	Washing machine	Dryer	Kitchen appliances	Dish washer	Microwave	Refrigerator	Household appliances	Smartphones
aApp,m	1	1	1	0	0	0	3	0	0	0	3	1

After executing the procedure of over writing obviously unrealistic numbers of electronic appliances, the percentage of obviously wrong data can be derived and is given for each milieu in the following.

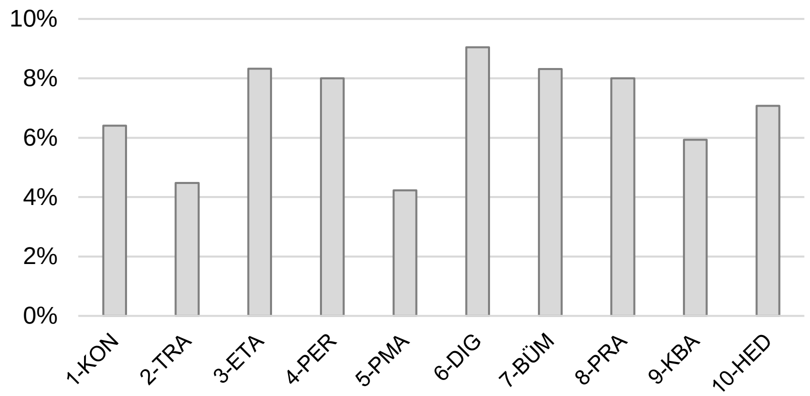

Figure 19: Percentage of obviously wrong data regarding the number of electronic appliances related to each milieu according to the procedure given within equation (29) and (31) in order to maintain a high number of questionnaires. It can be observed, that 7% of n=977 has been corrected.

That procedure has been saving 70 out of 977 answers, which means 7% of all answers has been corrected according to procedure given in equation (31). The final number of all electronic appliances related to each milieu has been determined in the following.

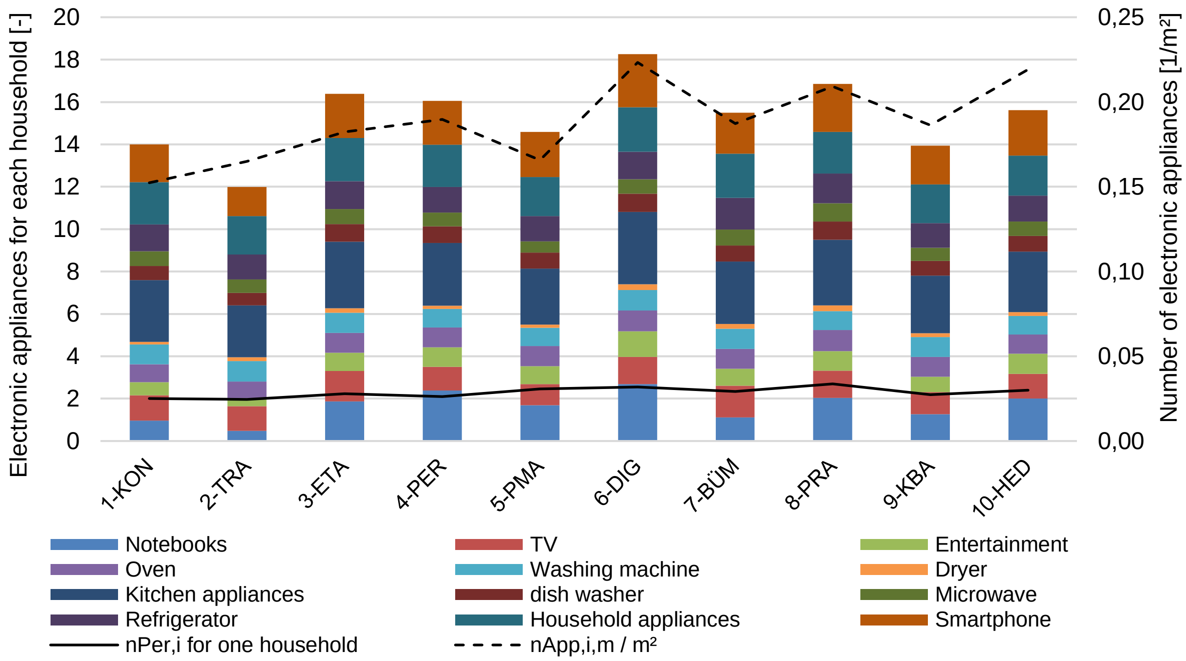

Figure 20: Electronic appliances related to each milieu and household - $n_{App,i,m}$. The correlation of $n_{App,i,m}$ to the real number of electronic appliances performs insufficiently.

While Figure 20 shows the number of electronic appliances related to the gross floor area of each household $n_{App,i,m}$ [1/m²], Figure 21 shows the same number related to 1 person and GFA $n_{App,i,m,GFA}$ [$1/n_{Per}.m^2$]. The differences are significant, even the data in each figure are the same. Thus, the level of balancing the amount of electronic appliances becomes important. It becomes also clear that the number of occupants $n_{Per,i}$ is not directly related with the amount of electronic appliances $n_{App,i,m}$. This fact emphasizes the approach to balance per person and GFA even more. Thus, the number for electronic appliances refers to one Person and $GFA_{(i)}$ ($n_{App,i,m,GFA}$), as given in Figure 21.

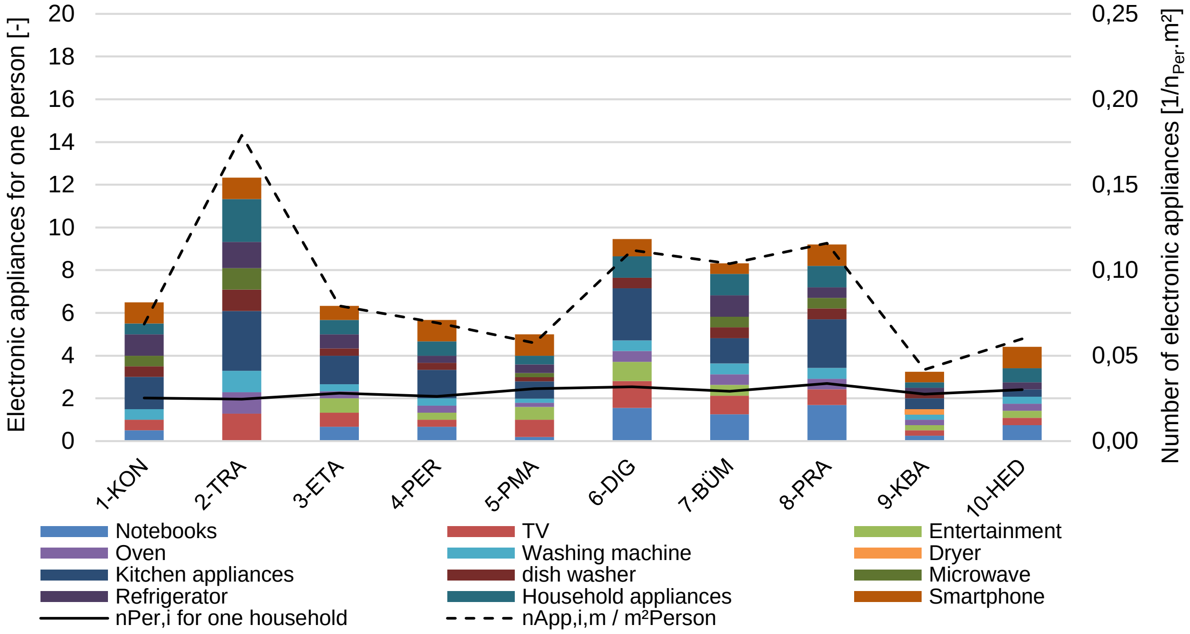

Figure 21: Electronic appliances related to each milieu and person - $n_{App,i,m,GFA}$. The correlation of $n_{App,i,m,GFA}$ to the real number of electronic appliances performs more accurate than ratio number of appliances to GFA.

The correlation of $n_{App,i,m,GFA}$ to the real amount of electronic appliances performs much better than balancing only at the level of $n_{App,i,m}$ (given in Figure 20). Thus, the mean value for each milieu $n_{App,i,m,GFA}$ can be considered as more reliable in order to determine the number for each electronic appliance. Therefore, $n_{App,i,m,GFA}$ can be used for further projects if detailed data coming from e.g. questionnaires are not available. However, this method focuses on each answer individually in order to determine the milieu based electrical load – see equation (37). As the number of electronic appliances is known, the duration of their use have been asked analogously. Thus, 6 sub categories have been had subject for more detailed data in order to cluster all appliances by application (e.g. electronic appliances regarding the entertainment are clustered to $t_{Att,i,TV}$ according to Figure 22).

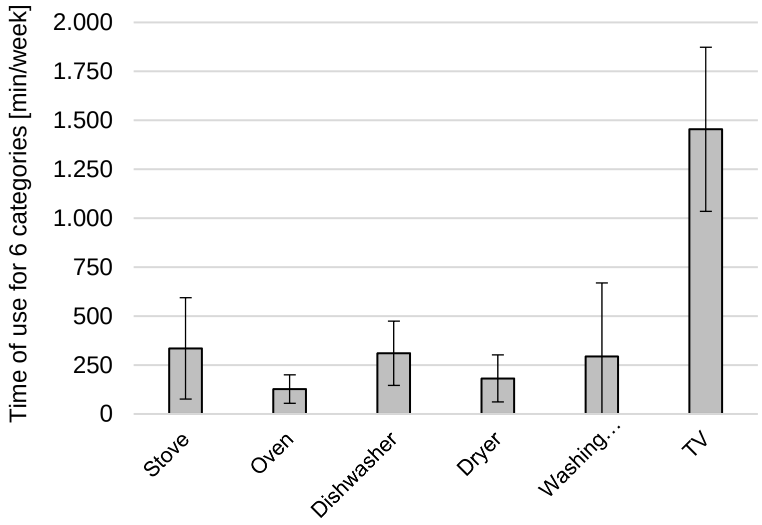

Figure 22: Running times $t_{Att,i,m}$ for each category including the standard deviation divided into 6 sub categories within all milieus before the correction procedure.

The results given in Figure 22 indicate the numbers in terms of minutes per week before the correction procedure. Figure 22 shows clearly, that the range including the standard deviations differs a lot and thus, makes the raw data inappropriate for further actions. However, analogues to the procedure in the course of calculating $n_{App,max,i,m}$, an algorithm has been used to over write obviously unrealistic data instead of deleting them.

$$t, App, i, m < n, Att, i = t, App, i, m \quad (32)$$
$$t, App, i, m > n, Att, i = t, App, i, m \pm SD, i, m \quad (33)$$

$t_{App,i,m}$	*Given running times for each electronic appliance related to each answer within a milieu (i) … [min/week]*
$n_{Att,i}$	*Attendance for each answer within a milieu (i) according to Figure 16 … [min/week]*
$SD_{i,m}$	*Standard deviation for that specific electronic appliance related to each milieu … [min/week]*

The algorithm given in equation (32) and (33) corrects mismatches regarding the general attendance and the given number for the time of use. This procedure ensures that electronic appliances are only used when the participants are attendant and thus, 34 answers have been over written according to equation (33). That procedure has been used for each electronic appliances related to the sub categories given in Figure 22.

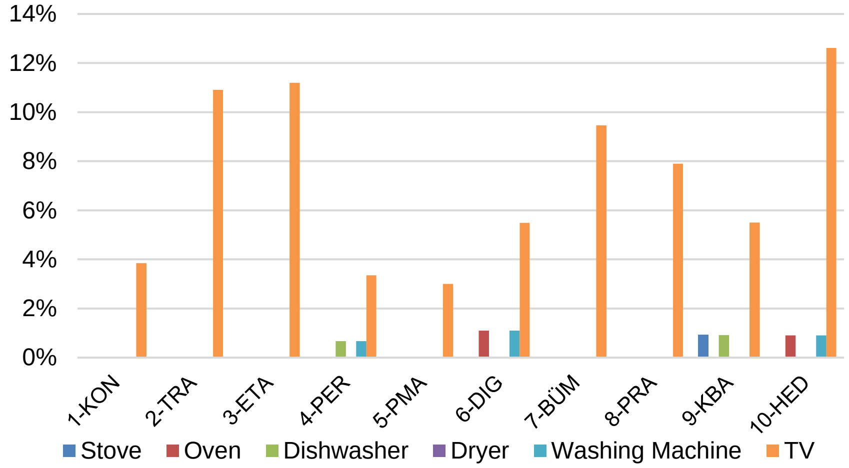

Figure 23: Relative amount of corrections regarding the time of use $n_{Att,i,m(t)}$ related to each milieus attendances according to the procedure given within equation (33), in order to maintain a high number of questionnaires.

As Figure 23 clearly shows, the sub category for televisions in terms of time of use have been over written the most (e.g. $t_{App,i,TV} > n_{Att,i}$ [min/week]). Overall, roughly 1% of n=977 have been over written. Additionally, that procedure has been used to over write obviously overestimated running times for each category. Thus, each category has been set up with an appropriate limit in terms of running times.

Table 17: Limited running times for each category, in order to over write obviously overestimated data given by the participants.

	Stove	Oven	Dishwasher	Dryer	Washing machine	TV
$t_{max,App,i,m}$ [hr/day]	2	2	4	2	1	8
$t_{max,App,i,m}$ [min/week]	840	840	1 680	840	420	3 360

According to Table 17 and analogues to Figure 23, the correction factors based on equation (34) and (35) are given in the following.

$$t, App, i, m < t, max, App, i, m = t, App, i, m \qquad (34)$$

$$t, App, i, m > t, max, App, i, m = t, App, i, m \pm SD, i, m \qquad (35)$$

$t_{App,i,m}$	*Given running times for each electronic appliance related to each answer within a milieu (i) ... [min/week]*
$t_{max,App,i,m}$	*Limited running times for each category, according to Table 17 ... [min/week]*
$SD_{i,m}$	*Standard deviation for that specific electronic appliance related to each milieu ... [min/week]*

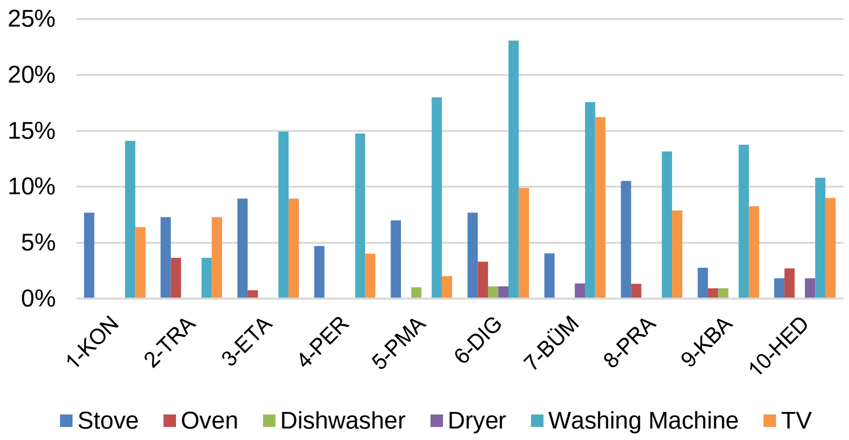

Figure 24: Relative amount of corrections regarding $t_{Att,i,m}$ related to each categories limits (Table 17) according to the procedure given in equation (34) and (35), in order to maintain a high number of questionnaires.

Overall, roughly 5% of n=977 have been over written. However, it becomes clear that especially data regarding the running times for televisions and washing machines have a tendency to get overestimated. Even the running time limits given in Table 17 can be considered as conservative. Additionally to the results regarding the attendances given within chapter 3.4.1, each participants indicates for each category the time of use with regard to the time cluster given in Table 15. Thus, not only the running times $t_{App,i,m}$, but also the time of use $n_{App,m(t)}$ with respect to both, weekday and weekend day, are known. The results for all categories regarding the time of use as well as the running times are given in the following.

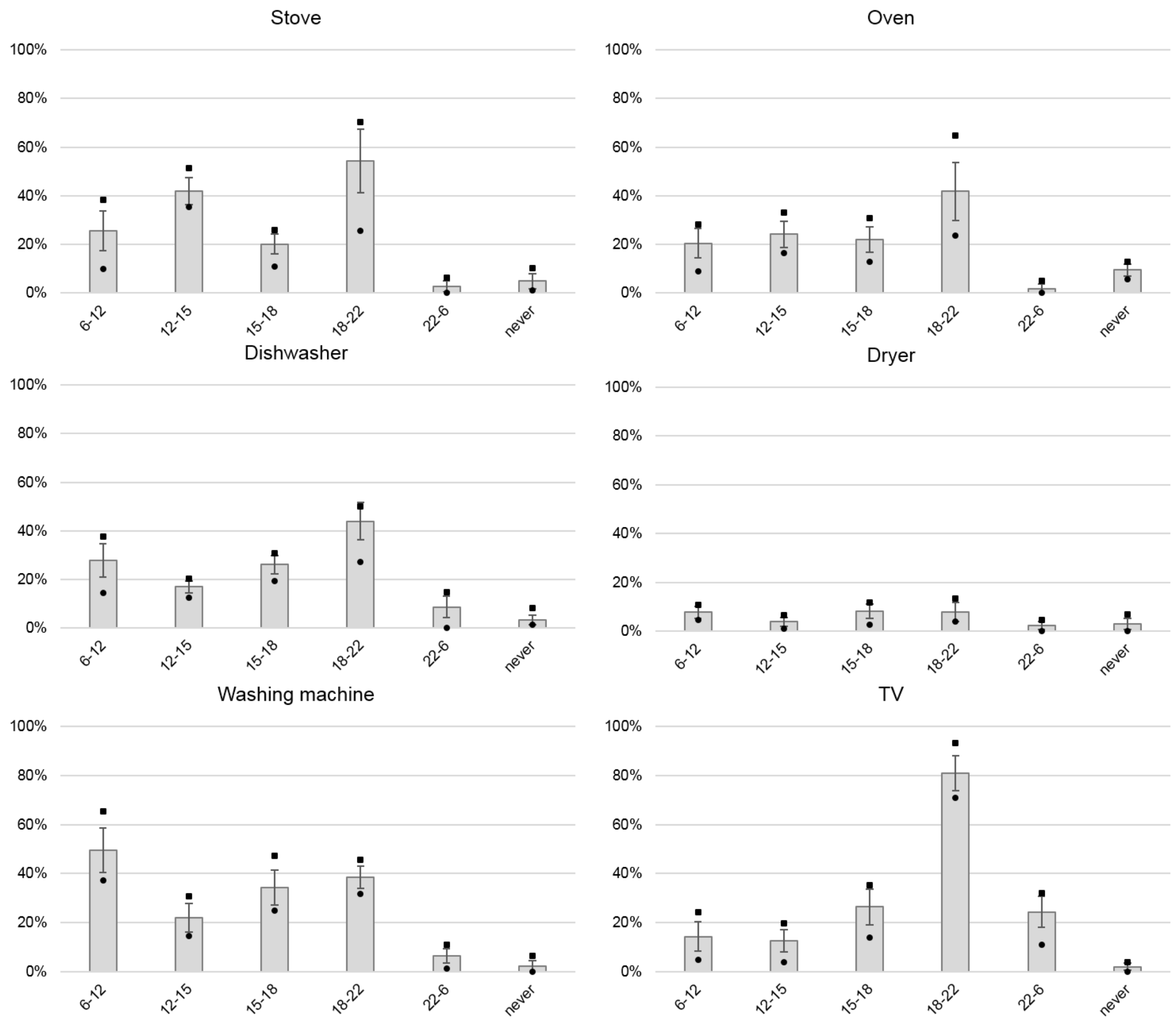

Figure 25: Time of use $n_{Att,i,m}(t)$ for each category including the standard deviation as well as the maximum and minimum throughout all milieus after the correction procedure.

Figure 25 shows the mean value for $n_{Att,i,m}(t)$ for each category. Each category shows an accurate as well as realistic characteristic for the time of use. Thus, no corrections regarding the raw data have been done. The results regarding the running times $t_{Att,i,m}$ with respect to the correction procedure given in equation (34) and (35) are given in the following.

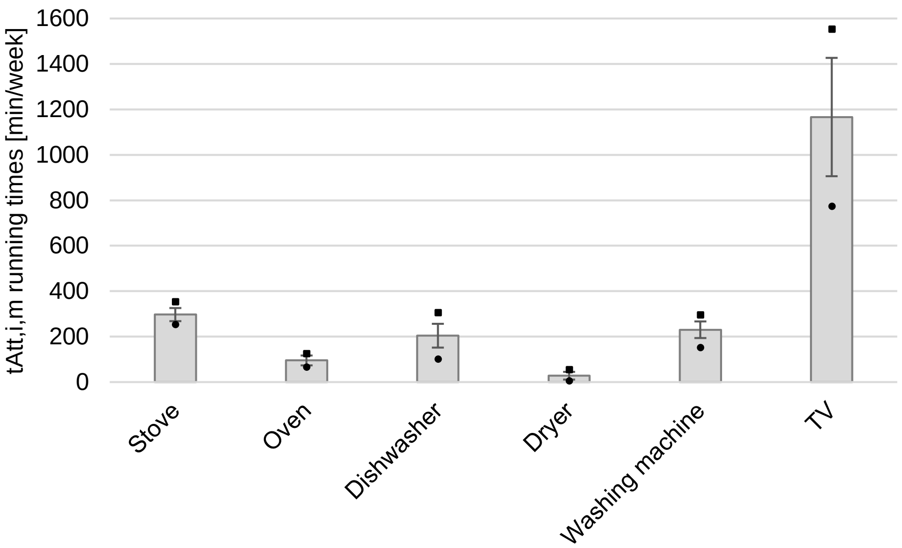

Figure 26: Running times $t_{Att,i,m}$ for each category including the standard deviation as well as the maximum and minimum throughout all milieus after the correction procedure.

As already indicated within Figure 23 ($n_{Att,i,m}$) and Figure 24 ($t_{Att,i,m}$), some corrections due to overestimated answers have been made. Although the relative number for each correction factor is relatively low (for $n_{Att,i,m}$ = 1% and for $t_{Att,i,m}$ = 5%), the results regarding the running times have been improved significantly, see comparison Figure 22 and Figure 26. In order to generate a time sensitive load profile, the running times for each category have been directly divided to the given time of use according to equation (36).

$$t, App, i, m(t) = t, Att, i, m(t) \times n, Att, i, m(t) \qquad (36)$$

$t_{App,i,m(t)}$	*Time sensitive share regarding the running time with regards to the time cluster given in Table 15 … [%]*
$t_{Att,i,m(t)}$	*Calculated running times for each category within a milieu (i) … [%]*
$n_{Att,i,m(t)}$	*Given time of use due to the questionnaires for each answer and category … [%]*

As $t_{App,i,m(t)}$ is known, the electrical power for each electronic appliance is necessary in order to generate a time sensitive electrical load profile. Due to this thesis is not focusing on the characteristics for a various of electronic appliances, the assumed electrical power for each appliance is given in the following.

Table 18: Electrical power for all considered electronic appliances according to the findings of [WID09] and [GHA11].

	Notebook	TV	Entertainment	Oven	Washing machine	Dryer	Kitchen appliances	Dish washer	Microwave	Refrigerator	Household appliances	Smartphones
$P_{App,m,use}$ [W]	50	70	30	600	120	120	50	120	600	145	30	5
$P_{App,m,standby}$ [W]	5	5	6	1	1	1	1	1	1	-	0	0

Based on the electrical power given in Table 18 and equation (36), the electrical load profile for each milieu can be created using equation (37).

$$P,el,i(t) = t,App,i,m(t) \times P,Att,m,use + (1 - t,App,i,m(t)) \times P,Att,m,standby \qquad (37)$$

$t_{App,i,m(t)}$	*Time sensitive share regarding the running time with regards to the time cluster given in Table 15 ... [%/day]*
$P_{App,i,m,use}$	*Electrical power for each electronic appliance when used ... [W]*
$P_{App,i,m,standby}$	*Electrical power for each electronic appliance when stand by ... [W]*
$P_{el,i(t)}$	*Time sensitive electrical power for each milieu ... [W]*

However, due to the data of [WID09] and [GHA11] are not related to Vienna, the input data regarding the electrical power given in Table 18 have been adjusted as long as the annual electrical consumption over all milieus meets the results of [ECON16].

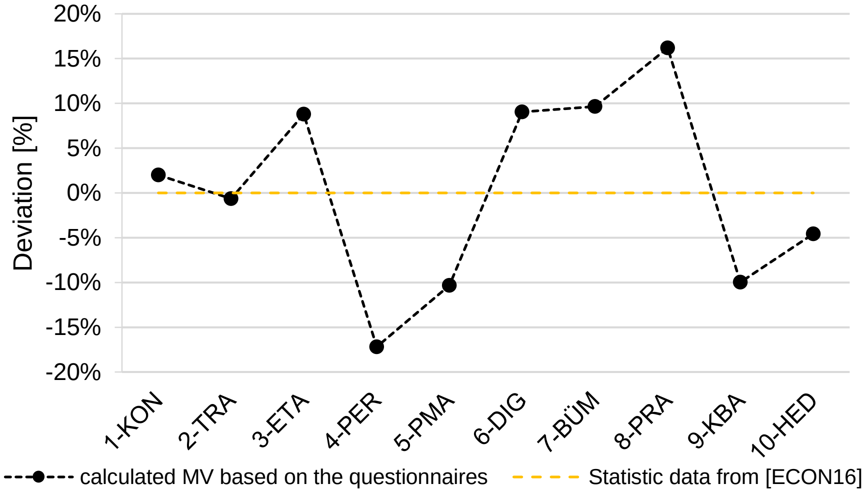

Figure 27: Deviation of the calculated mean value ∑ P_{el} according to equation (37) compared with statistic data from [ECON16].

Figure 27 shows clearly, that the deviation in terms of the annual electricity consumption for all milieus ranges from roughly +20% to -15%, which is a considerable proportion. The results given in Figure 30 even emphasizes the milieu oriented approach. The final results for the time sensitive electrical load profiles, based on equation (37), are given in the following.

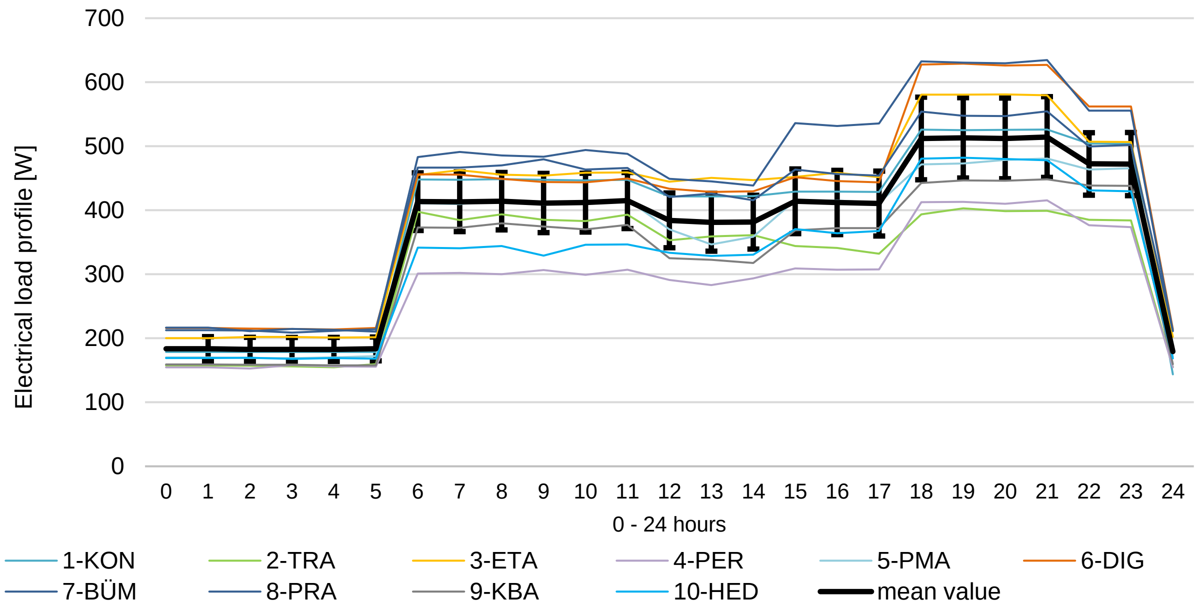

Figure 28: Final time sensitive electrical load profile for each milieu, taken into account a week day. Additionally, the differences regarding the mean value including the SD over all milieus highlights the significance of a milieu oriented approach.

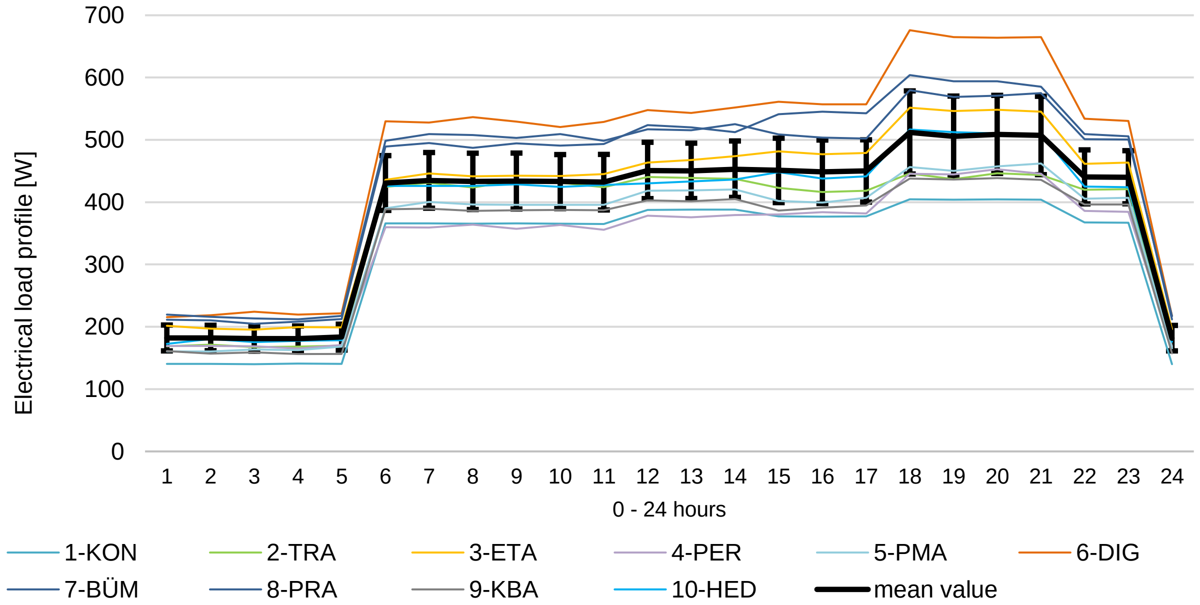

Figure 29: Final time sensitive electrical load profile for each milieu, taken into account a weekend day. Additionally, the differences regarding the mean value including the SD over all milieus highlights the significance of a milieu oriented approach.

Figure 28 and Figure 29 show the final results for the milieu oriented electrical load profile. The results show clearly the importance of that milieu oriented approach. Not only the range of the bandwidth considering the mean value including the standard deviation, but also the given maximum and minimum loads demonstrates the wide variety taking into account 10 milieus. As the time cluster given within Table 15 can be considered as rough, the profile doesn't have the capability to distinguish different electrical loads within a certain time cluster. Thus, the profiles are not as smooth as e.g. high resolution metered data. However, due to time restrictions within the questionnaire process [HAU16b], more specific data couldn't be gained. Due to the correction procedure is using the standard deviation $SD_{i,m}$ randomly in order to over write, each milieu based electrical profile has been created 1000 times. Thus, the final mean value $P_{el,i(t)}$ given in equation (37) is based on 1000 calculated profiles related to each milieu. Finally, based on equation (37) the density function can be dissolved.

$$DF,occ,BC,k,i(t) = \frac{P,el,i(t) \times \frac{1}{\eta,el}}{GFA,i,BC} \tag{38}$$

$DF_{Occ,BC,k,i(t)}$	*Density function for each time step (t) related to a certain building (BC) within the building cluster, HVAC design and milieu (M1 – M10) with regard to E_t … [W/m²]*
$P_{el,i(t)}$	*Electrical load due to the occupation for each time step related to the real milieu based occupancy – see equation (37) … [W]*
$GFA_{i,BC}$	*Gross floor area related to $n_{Per,i}$ according to Table 14 … [m²]*
η_{el}	*Electrical efficiency ratio according to Table 7 … [-]*

Analogues to the density function related to office buildings, equation (38) derives the final density function taking into account the electrical loads related to residential buildings. Furthermore, $\sum P_{App,i(t)}$ has been used as input data for the simulation engine as explained within Table 28.

In order to emphasize the importance and enhance the knowledge of a milieu oriented approach, more detailed results related to certain parameters are given in the following. Due to the results given within Figure 28 and Figure 29 are related to the questionnaires according to [HAU16b], the generated electrical load profiles apply only to the Vienna area. However, in order to make them comparable in terms of further validations, the electrical load profiles have been adjusted. Thus, all profiles assuming an annual electrical consumption of 1000 kWh/yr. Thus, makes the profiles comparable to the well disseminated data of [BGW06].

First, Figure 30 shows an electrical load profile related to different buildings in terms of age and size. It can be clearly observed, that the buildings age and its size do not impact the specific load profile characteristics at all. Therefore, further results (see chapter 4.2.1 and 4.2.2) have not been related to a certain building size nor its age.

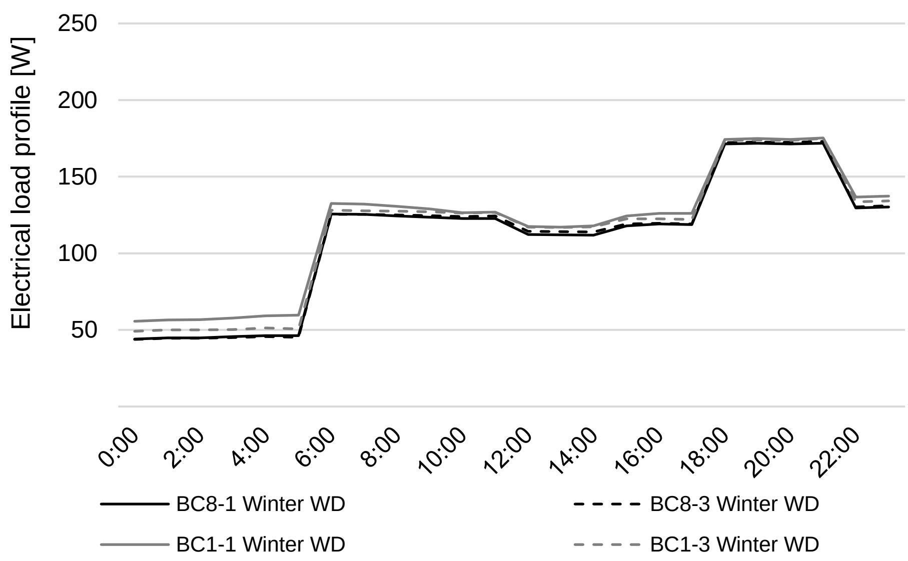

Figure 30: Comparison of the milieu based electrical load profile (mean value for all milieus) considering a winter week day (WD) with respect to BC1-1, BC1-3, BC8-1 and BC8-3, assuming an unified consumption according to [BGW06] with regard to E_b of [IEA13]. No significant influence of the building age and its size onto the electrical load profile characteristic can be observed.

Since the qualitative and quantitative electrical load profile is known, the predicted electrical energy consumption related to the occupation can be calculated.

$$Qel, i = \sum_{n=1}^{8760} P, el, i(t) \times \frac{1}{\eta, el} \tag{39}$$

$Q_{el(i)}$	*Calculated DHW demand for each milieu based on raw data with regard to E_b... [kWh]*
$P_{el,i(t)}$	*Time sensitive electrical power for each milieu ... [W]*
η_{el}	*Electrical efficiency ratio according to Table 7 ... [-]*

According to equation (39), the predicted annual electrical consumption can be derived as an overall mean value as well as for all milieus specifically. The results are given in Figure 31, respectively in Figure 32 when considering all specific milieus.

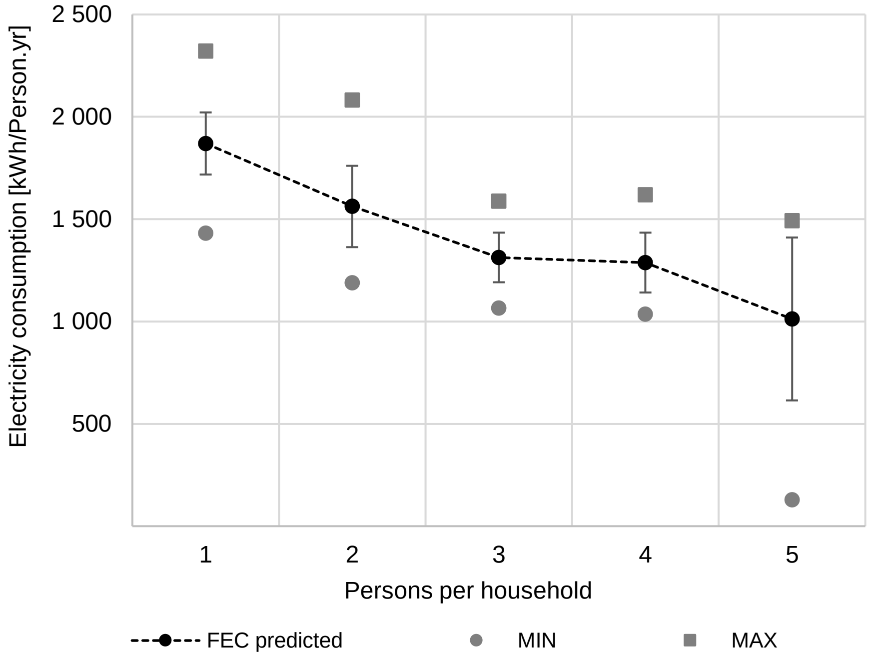

Figure 31: Electricity demand (with regard to E_b of [IEA13]) for all milieus related to all electronic appliances with respect to the standard deviation regarding the mean value (black dotes), based on the answers of the questionnaires. Additionally, the absolute minimum and maximum values (grey dotes) over all milieu based on the questionnaires are highlighted.

Due to Figure 31 addresses only the overall mean value, specific milieu based characteristic cannot be addressed. Thus, Figure 32 shows all variances between all milieus regarding their annual electricity consumption related to the number of persons per household.

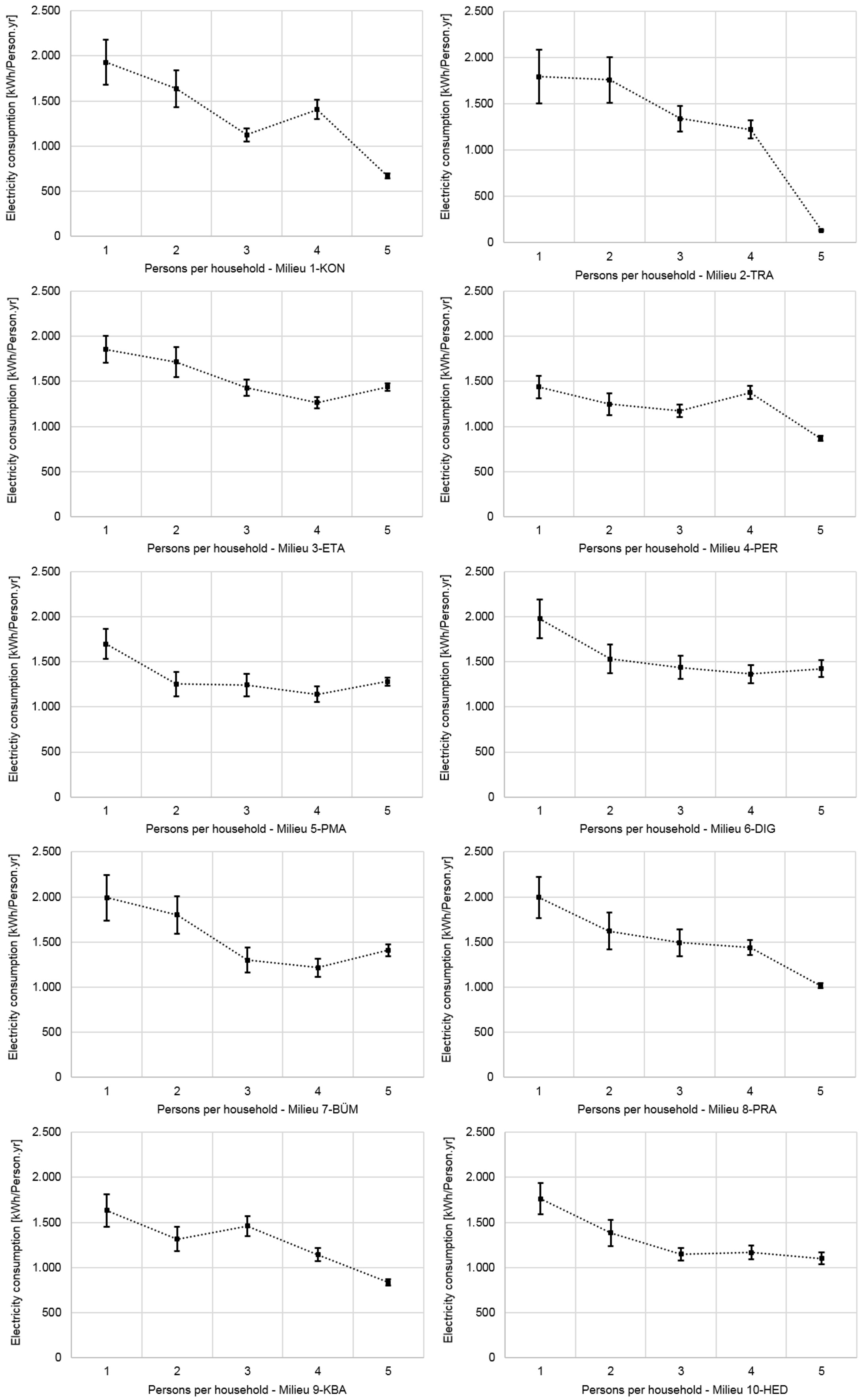

Figure 32: Spec. annual electricity consumption characteristics for each milieu related to the number of persons. Almost each milieu shows its own characteristics regarding the profiles quantity and quality. Thus, makes this result highly valuable in order to force the method of social differentiation.

It can be observed, that almost every milieu has its own characteristics. Furthermore, the maximum and minimum annual electricity consumption, are much greater than the overall mean value. Thus, as already given within the final equations (37) and (38), all further results are milieu dissolved. Due to metered data regarding the annual electricity consumption are likely available, makes this indicator given in Figure 32 highly comparable. This leads to the approach, to compare specific milieu based annual electricity consumption characteristics with metered data in order to determine the specific milieu within that metered building. However, this hypothesis will be subject of further interdisciplinary research activities.

In order to provide comparable electrical load profiles, the following results are subject to a unified annual electrical consumption according to [BGW06]. This fact enables to make the results more unrelated to the considered case URBEM with focus on Vienna. However, although the following results are not subject in order to create time sensitive electrical load profiles, the results have been used in the course of the validation procedure within chapter 4.2.1.

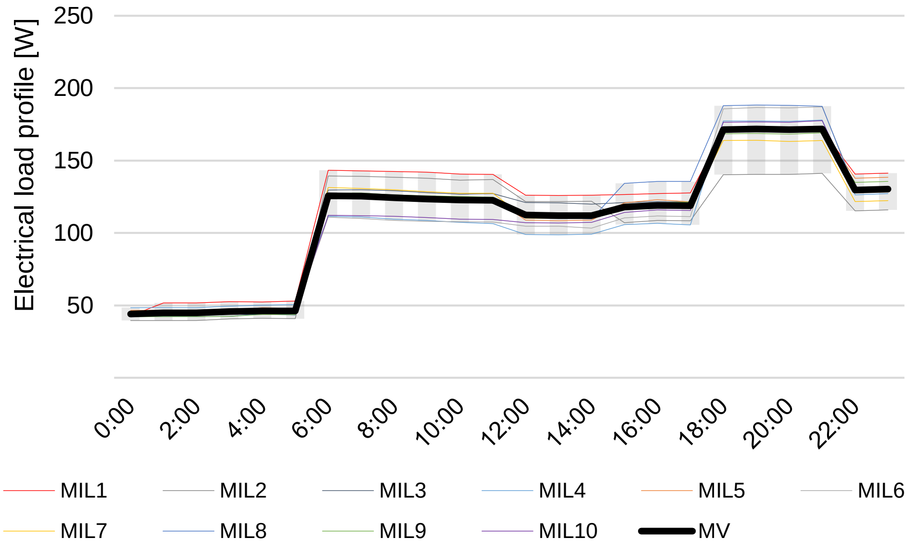

Figure 33: Differences regarding the electrical load profile considering all milieus for a winter week day, with regard to E_b of [IEA13]. The bandwidth can be considered as range for the electrical load profile, but only related to the deviation of the mean values (MV) for each milieu.

Analogues to the URBEM / Vienna related electrical load profiles based on the questionnaires of [HAU16b] given in Figure 28 and Figure 29, Figure 33 visualizes milieu based electrical load profiles with regard to an annual unified electrical consumption. In order to give an idea regarding the bandwidth due to the milieu oriented approach, Figure 34 shows clearly the maximum bandwidth based on the mean values for each milieu. However, according to Figure 31 the maximum and minimum annual electrical energy consumption exceeds the given bandwidth based on the mean values significantly. Thus, the results distinguish between all milieu, but do not address individual peaks.

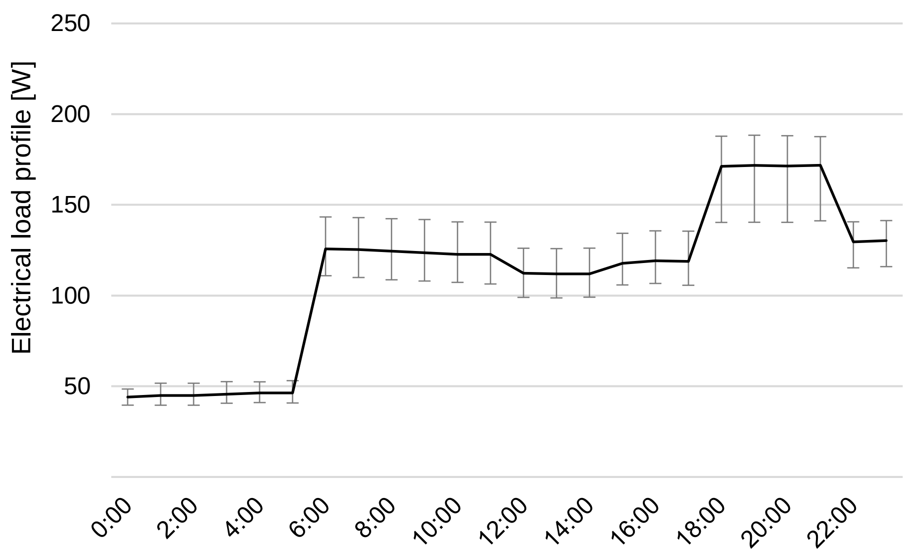

Figure 34: Milieu based mean value for the electrical load profile, including the maximum bandwidth, with regard to E_b of [IEA13]. As in Figure 33 briefly described, the bandwidth is related to the mean values for each milieu and thus, considers not the maximum and minimum values within each milieu (addressed in Figure 31).

The last result within this chapter addresses the differences regarding the summer and winter period. Figure 35 shows clearly a higher electrical load during the winter period.

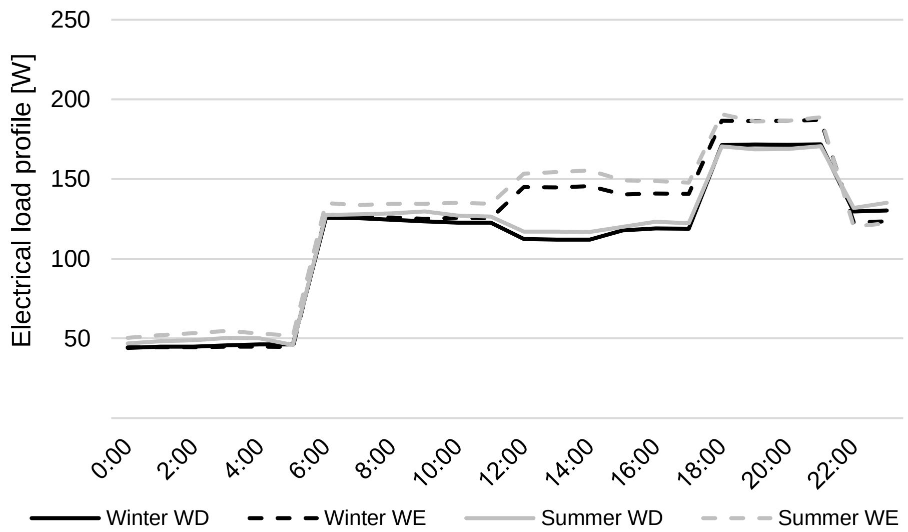

Figure 35: Differences of the electrical load profile characteristic considering a week day (WD) and weekend day (WE) as well as winter and summer, with regard to E_b of [IEA13].

3.4.3 Milieu based domestic hot water

Based on the results of the questionnaires for each milieu, Figure 36 represents the raw data of for n=977. This data set represents the amount of showers and baths for one week and one person.

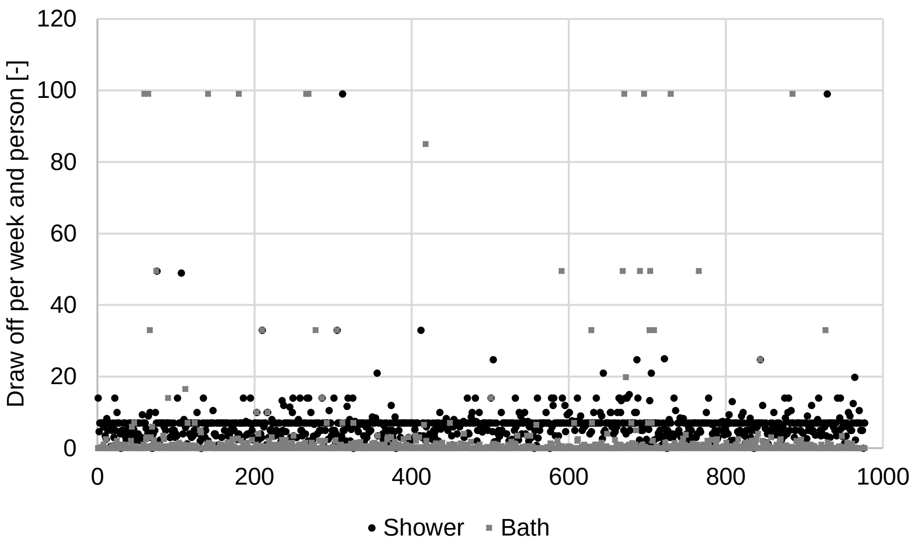

Figure 36: DHW raw data from the questionnaires (n=977) regarding the amount of showers and baths per person and week.

As Figure 36 and Figure 37 underline, the majority of people having a shower 6.69 times a week and 2.29 times a week a bath.

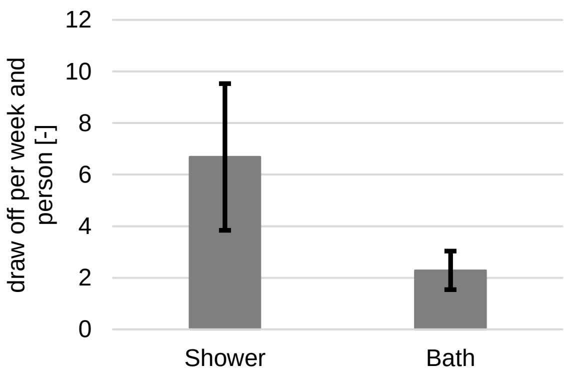

Figure 37: Number of draw offs per week and person with regard to shower and bath for n=977.

As some samples obviously exceeds realistic shower and bath behavior, the model uses some restrictions, based on the standard deviation of Figure 37, given in equation (40) and (41).

$$n, max, drowoff, shower = n, Per, i \times 7 \times 1.5 \tag{40}$$

$$n, max, drowoff, bath = n, Per, i \times 7 \times 1.1 \tag{41}$$

$n_{max,drowoff,shower}$	*Number of draw off for shower per week according to the raw data of Figure 36 and Figure 37… [-]*
$n_{max,drowoff,bath}$	*Number of draw off for bath per week according to the raw data of Figure 36 and Figure 37… [-]*
$n_{Per,i}$	*Persons per household for each milieu … [-]*

Thus, all answers with a greater amount than $n_{max,drowoff,shower}$ and $n_{max,drowoff,bath}$ have not been considered. In fact, 37 answers haven been deleted and thus, $n_{(i)}$=940 (for all milieus). As the draw off rate for each category given within Table 10 is known, the mean values of the DHW demand based on the raw data are given in Figure 38. According to the Austrian Standards Institute [ONO11] the specific energy consumption related to the domestic hot water related to residential buildings is 35 Wh/m²day which is equal to roughly 25 Liters/Person.day or 9 m³/Person.year (assuming GFA=35m²/Person, ϑ_{DHW}=55°C and ϑ_{supply}=10°C as well as E_b according to [IEA13]). The same comparison can be made with data from [SIA06]. Thereby the domestic hot water demand is roughly 15 m³/Person.year. Compared to both standards, the domestic hot water demand based on the raw data from [HAU16b] are slightly overestimated and thus, makes it necessary to use the raw date as input for the buildings simulation and not as a final result. This might be due to the fact that the participants are not fully aware of their annual domestic hot water demand. However, due to the values from both standards refer to E_b according to [IEA13] and the final results given in Table 29 refer to E_t according to [IEA13], a clear comparison can be hardly made. Nevertheless, assuming the DHWs systems losses are as high as the demand, the simulated DHW consumption has a good match to both standards.

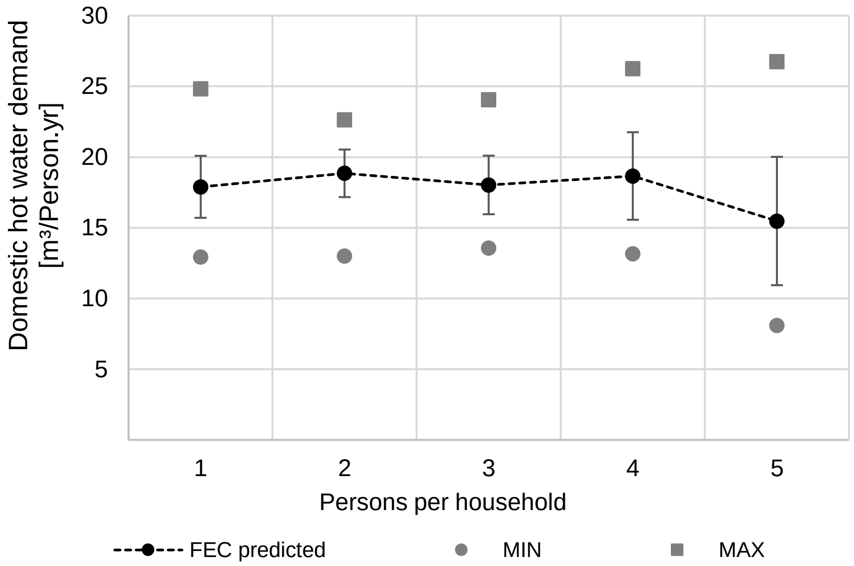

Figure 38: Domestic hot water demand (with regard to E_b of [IEA13]) with respect to the standard deviation regarding the mean value (black dotes) for all milieus, based on the answers of the questionnaires n=940. Additionally, the absolute minimum and maximum values (grey dotes) for all milieus are highlighted.

Due to Figure 38 addresses only the overall mean value, specific milieu based characteristic cannot be addressed. Thus, Figure 39 shows all variances between all milieus regarding their DHW demand behavior related to the number of persons per household. It can be observed, that almost every milieu has its own characteristics. Furthermore, the maximum and minimum DHW demand of certain milieus, are much greater than the overall mean value. Due to metered data regarding the DHW demand are likely available, makes this indicator given in Figure 38 highly comparable. This leads to the approach, to compare specific milieu based DHW demand characteristics with metered data in order to determine the specific milieu within that metered building. However, this hypothesis will be subject of further interdisciplinary research activities.

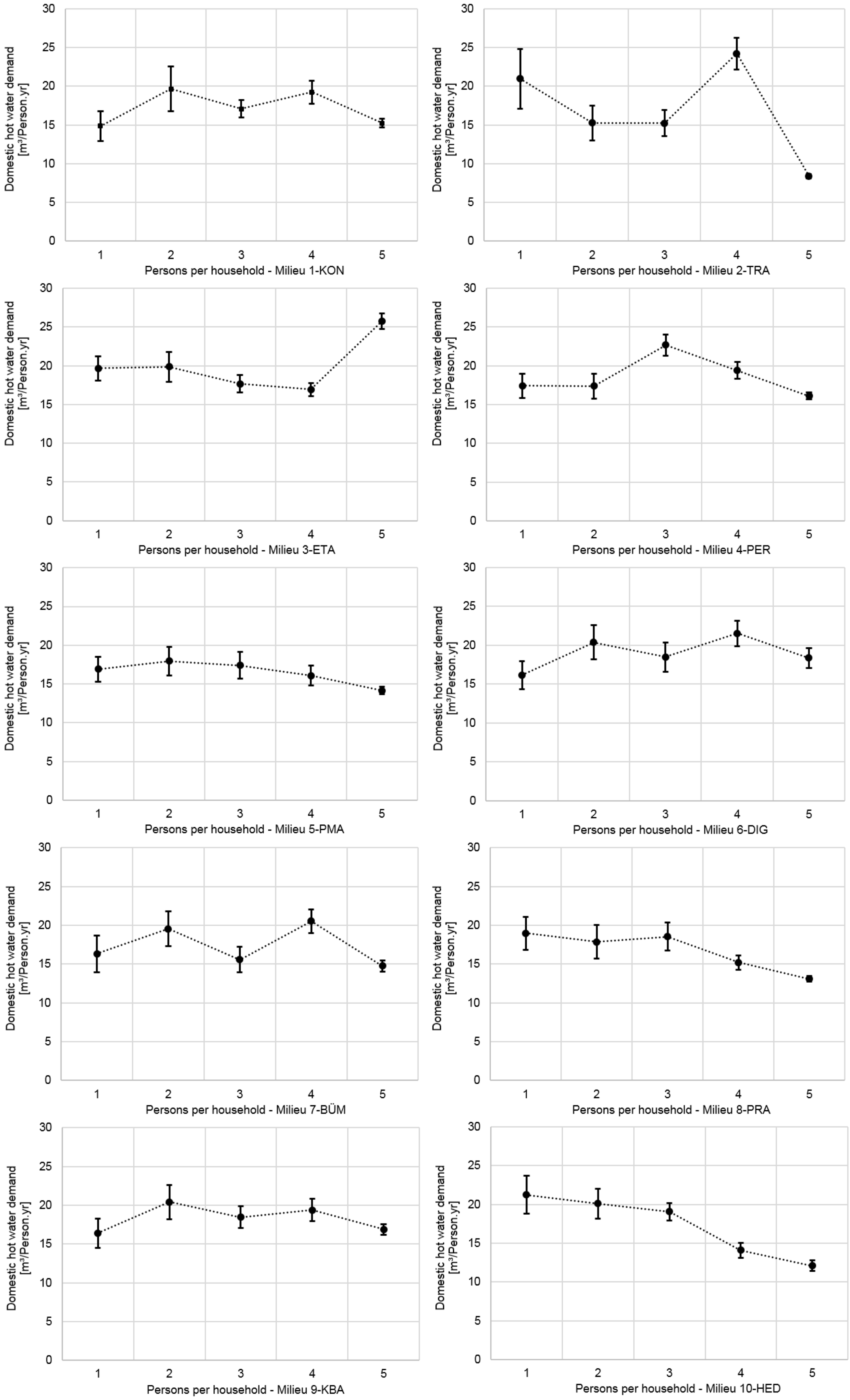

Figure 39: Spec. DHW demand characteristics for each milieu related to the number of persons. Almost each milieu shows its own characteristics regarding the profiles quantity and quality. Thus, makes this result highly valuable in order to force the method of social differentiation.

In order to compare the DHW demand for each milieu, Figure 40 distinguishes the mean value regarding the specific DHW demand of all 10 milieus.

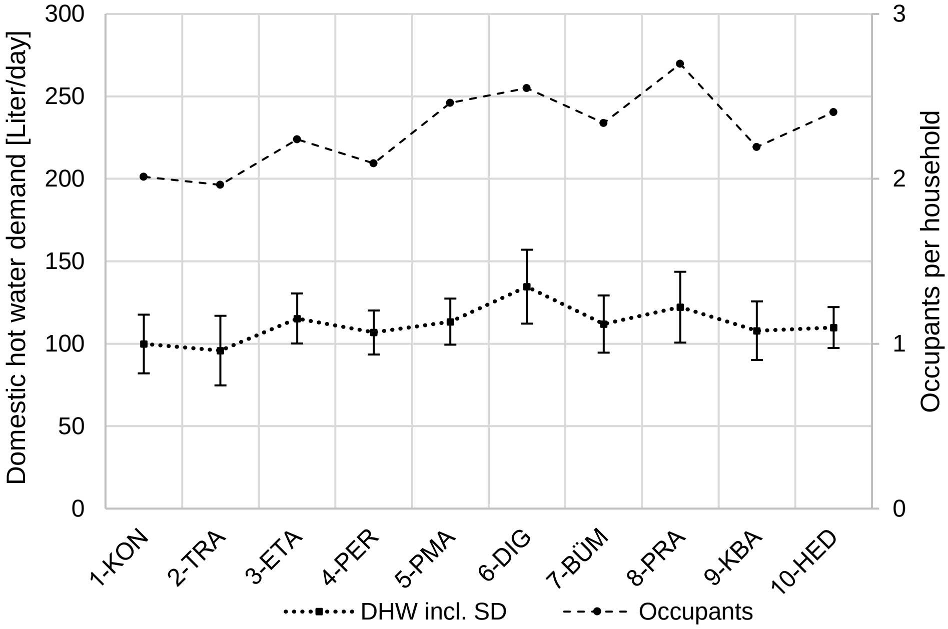

Figure 40: Milieu based domestic hot water demand per day (with regard to E_b of [IEA13]), in accordance to the number of occupants per household. It can be observed, that the number of people per household does not correlate to the specific DHW demand including the standard deviation (SD).

Considering the number of occupants and the milieu based DHW demand given in Figure 40, the DHW demand is varying significantly throughout all milieus. Furthermore, the number of occupants per household shows no clear correlation to the specific DHW demand. In order to balance the energy demand at the level of E_b, equation (40) is given in the following.

$$QDHW,i = \frac{365 \times m(i) \times (\vartheta, DWH - \vartheta, supply) \times c, water}{GFA, i} \qquad (42)$$

$Q_{DHW(i)}$	*Calculated DHW demand for each milieu based on raw data with regard to E_b... [kWh/m²yr]*
m_i	*Draw off per day according to Figure 40... [kg/day]*
ϑ_{DHW}	*Temperature level for hot water ... [°C]*
ϑ_{supply}	*Temperature lever of supply water ... [°C]*
c_{Water}	*Specific heating capacity of water ... [kJ/kgK]*
GFA_i	*Mean value for the gross floor area related to each milieu ... [m²]*

Equation (40) shows how to transform raw data into useful energy demand indicators. The results for the specific DHW demand $Q_{DHW(i)}$ given within Figure 41 show, that the specific domestic hot water demand will be a more reliable value rather than the absolute DHW demand per day given in Figure 40.

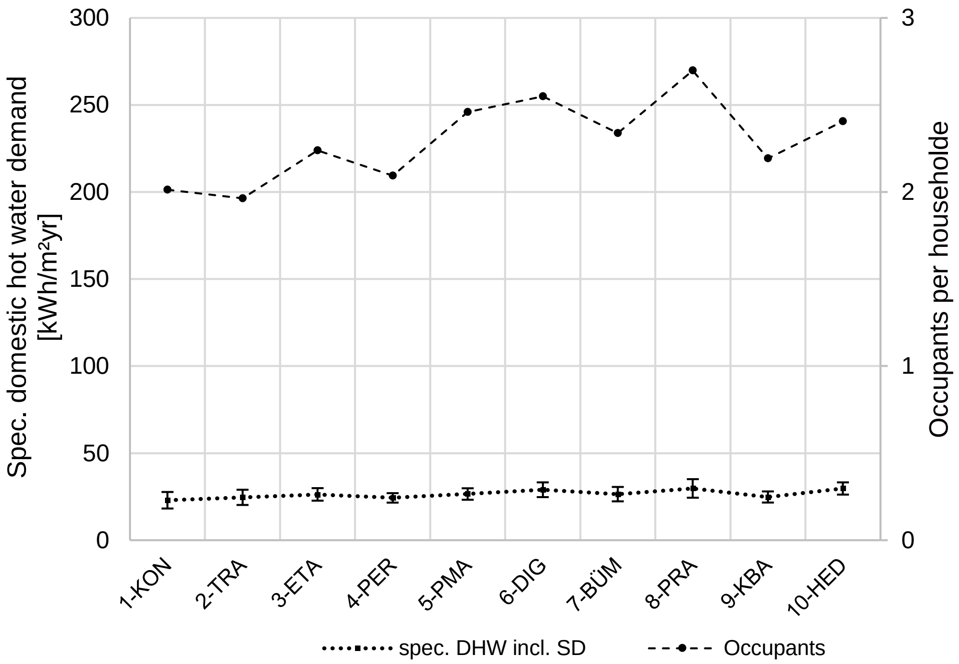

Figure 41: Milieu based specific domestic hot water demand (with regards to E_b of [IEA13]) related to the mean value of occupants per household for each milieu. Those results are based on the annual DHW demand including the standard deviation (SD) and the mean value for the milieu dissolved GFA, taking into account ϑ_{DHW}=55°C and ϑ_{supply}=10°C.

The same findings can be seen when considering the annual domestic hot water demand compared to the specific hot water demand.

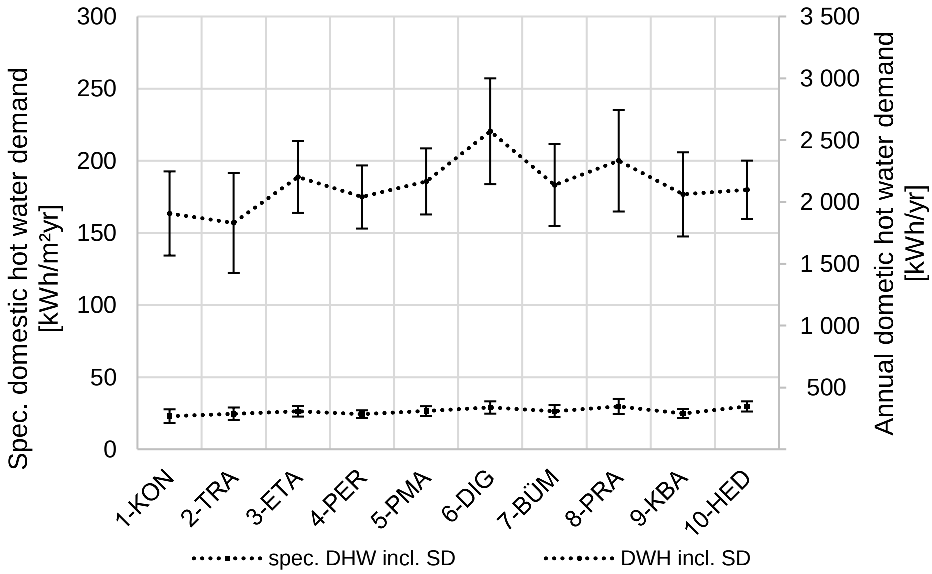

Figure 42: Comparison of the milieu based DHW demand for the specific and absolute value including the standard deviation (SD), with regards to E_b of [IEA13]. Those results are based on the annual DHW demand and GFA, taking into account ϑ_{DHW}=55°C and ϑ_{supply}=10°C.

Thus, the more specific the results, the smaller the standard deviation and the more accurate the results throughout all milieus. However, all given results within this sub chapter are related to raw data based on the questionnaires. Therefore, all results address only the demand with respect to the level of E_b [IEA13] and do not consider any correlation to dynamic attendances nor any technical parameters such as circulation pipes and system losses, towards balancing at the level of E_t [IEA13]. Thus, only the given milieu dissolved raw data, in terms of amount of showers and baths a day given in Figure 36, have been used as input parameters for the DHW model given within chapter 3.3.3.

3.4.4 Milieu based window behavior

The real behavior regarding opening the windows during the winter and summer period can be considered as a significant issue. Thus, in the course of the questionnaires, some questions address the differences in order to gain more information towards a milieu based approach. Due to the questionnaires, the number of windows, the frequency of opening them as well as the windows position (tilted or fully open) is known for both, the summer and winter period.

Table 19: Raw data regarding the window position according to the questionnaires of [HAU16b].

	Tilted windows	Fully opened windows	No data
Winter	162	771	44
Summer	162	767	38

The procedure to determine the air volume due to tilted or fully opened windows is given in [NEU15]. Furthermore, according to the equations given in [NEU15], the amount of windows, the opening time and the cross area of tilted or fully open windows is important and thus, that factor has to be determined. In order to do so, some assumptions have been made and are given in the following.

Table 20: Assumptions in order to determine the window positions according to the questionnaires [HAU16b].

τWindow,Winter min/hr	τWindow,Winter min/hr	pWindow -	$\vartheta_{A,min}$ (t) °C
15min	60min	0 … closed 0.1 … tilted 1 … fully open	10°C

Furthermore, this model assumes a 12 hours opening time for all windows a day due to the lack of data regarding more time sensitive data. However, during winter the opening hours are from 6am to 6pm (during the day) and during the summer from 6pm to 6am (during the night). In order to avoid any window opening actions at low ambient temperatures, $\vartheta_{A,min}$ =10°C.

$$if\ \vartheta A(t) \geq \vartheta A, min$$

$$p, Window, Winter, i(t) = nWindows, i \times p, Window, i \times \frac{\tau, Window, Winter}{60} \times \frac{1}{12} \quad (43)$$

$$if\ \vartheta A(t) \leq \vartheta A, min \quad (44)$$

$$p, Window, Winter, i(t) = 0$$

$$p, Window, Summer, i(t) = nWindows, i \times p, Window, i \times \frac{\tau, Window, Summer}{60} \times \frac{1}{12} \quad (45)$$

$\vartheta_A(t)$	*Ambient temperature… [°C]*
$\vartheta_{A,min}$	*Minimum temperature for open the windows … [°C]*
$p_{Window,i(t)}$	*Milieu based mean value for the windows position, considering the winter or summer time slot given in Table 20 … [-]*
$p_{Window,i}$	*Milieu based mean value for the windows position, according to the questionnaires… [-]*
$n_{Window,i}$	*Milieu based mean value for the amount of windows, according to the questionnaires… [-]*
τ_{Window}	*Opening time of all windows given in Table 20 … [min]*

According to the equations (43), (44) and (45), the results regarding the milieu based mean values for the windows position are given in the following.

Table 21: Milieu based mean values regarding the windows position taking into account summer and winter period. The given values have been used with regards to the 12 hours' time slot thus, those values represent the milieu based mean value for the windows position within 12 hours.

	MIL1	MIL2	MIL3	MIL4	MIL5	MIL6	MIL7	MIL8	MIL9	MIL10
$p_{Window,Summer}$ [-]	0.190	0.175	0.157	0.173	0.156	0.197	0.218	0.189	0.216	0.207
$p_{Window,Winter}$ [-]	0.051	0.048	0.043	0.040	0.039	0.042	0.040	0.042	0.049	0.039

Table 21 shows the results regarding the milieu based windows position taking into account the 12 hours' time slot for summer and winter. According to the equations regarding the air volume due to windows given in [NEU15], the simulation engine calculates the milieu based air volume on each time step. Thus, the time sensitive $p_{Window,i(t)}$ for each milieu has been used as input parameter for the simulation engine as given in Table 28.

3.4.5 Milieu based heating and cooling behavior

In the course of the questionnaires, all participants have been asked for the desired room temperature during the winter, as well as their cooling behavior during the summer. Based on the raw data from [HAU16b], the mean values for the desired winter temperature are given in the following.

Table 22: Mean values for the desired indoor temperatures during the winter, according to the raw data from [HAU16b].

	MIL1	MIL2	MIL3	MIL4	MIL5	MIL6	MIL7	MIL8	MIL9	MIL10
$\vartheta_{z1\_tair,w,i}$ [°C]	20.81	20.71	21.1	20.79	20.73	20.97	21.12	20.79	20.8	20.8

As can be seen within Table 22, the desired indoor temperature during the winter period does not vary significantly throughout all milieus. However, $\vartheta_{z1\_tair,w,i}$ has been used as input parameter for the simulation engine. Due to the simulation engine uses a 2-step controller with

1K hysteresis, the hysteresis has been used as offset in order to maintain the desired indoor temperature.

$$\vartheta, z1_{tair}, w, i = \vartheta, z1_{tair}, w, i + \vartheta, hys \qquad (46)$$

$\vartheta_{z1\_tair,w,i}$	*Desired indoor room temperature during the winter for each milieu based on the raw data of [HAU16b] ... [°C]*
ϑ_{hys}	*Temperature offset due to the 2-step controller ... [K]*

Analogues to previous results, the overall mean values in terms of the time of use for cooling appliances are given in the following.

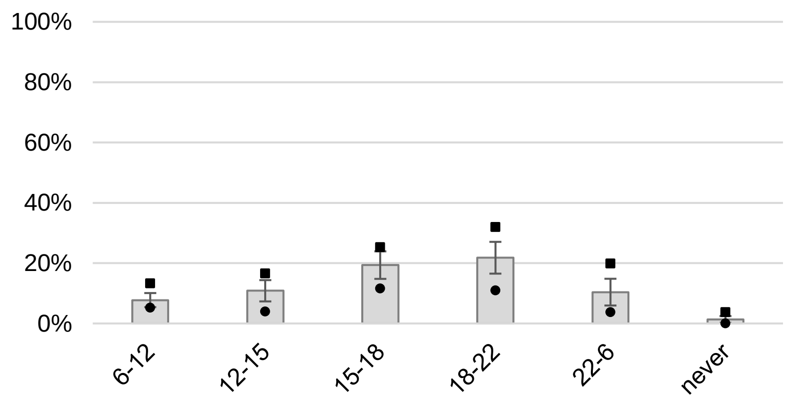

Figure 43: Time of use of cooling devices with respect to the standard deviation regarding the mean values for all milieus, based on the answers of the questionnaires n=977. Additionally, the absolute minimum and maximum values for all milieus are highlighted.

Figure 43 shows not only the low quantity of cooling devices within all milieus, but also the qualitative time of use within a day. The raw data of [HAU16b] given in Figure 43 have not been adjusted in the course of this procedure and thus, directly used for further calculations.

Due to time restrictions in the course of the questionnaires process, the desired indoor temperature during the summer haven't been asked. Thus, $\vartheta_{z1\_tair,s,i}$ has been set to 26°C. As already indicated in Figure 43, all participants have answered the questions whether they are used to cooling or not. The results based on the raw data for each milieu are given in the following.

Table 23: Relative amount of cooling devices throughout all milieus based on the raw data of [HAU16b] (yes 100% or no 0%).

	MIL1	MIL2	MIL3	MIL4	MIL5	MIL6	MIL7	MIL8	MIL9	MIL10
$n_{cool,i}$ [%]	8.97	3.64	10.45	10.07	4.00	10.99	10.81	6.58	11.01	9.01

Additionally, all answers are related to the given time cluster within Table 15. Thus, $n_{cool,i}$ for each milieu has been used as input parameter for the simulation engine as given in Table 28 as well as in order to determine the predicted energy consumption due to cooling $FEC_{BC,i,k(t)}$, given in equation (16).

3.4.6 Office buildings

As explained within chapter 1, this thesis focuses mainly on a milieu oriented approach taking into account residential buildings. However, the occupation based electrical load profile for office buildings is as important as those for residential buildings. In order to generate an accurate electrical load profile for office buildings, data from [HDZ14b] have been used. Those data refer to metered data of an 8 stories office building, by considering only the final electrical consumption within the occupied stories for both, building operation (such as blinds, lighting, controlling system) and occupation (such as computers, kitchen, printers, etc.). Both, the high resolution of these metered data and the high level of aggregation, make those data highly appropriate in order to generate a time sensitive load profile. Additionally, those raw data are subject for further calculations in order to make them more suitable, applicable, comparable as well as more realistic. Therefore, data from [PRO09] have been used to improve the qualitative load profile by using metered data regarding the realistic office occupation related to the real attendances. The profiles regarding the mean value for the general attendance according to [PRO09] are given in Figure 44.

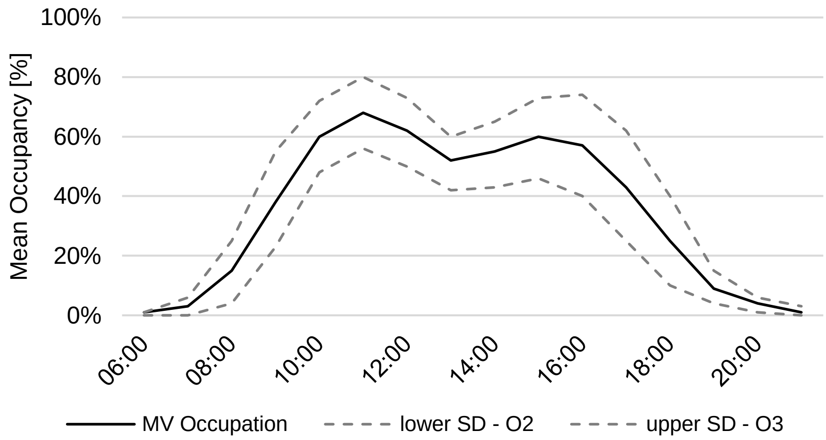

Figure 44: Profile regarding the mean value of the real attendances $n_{Att(t)}$ according to [PRO09] for a week day. While the black continuous line represents the mean value, the grey dashed lines represent the bandwidth in terms of the standard deviation.

Besides the results of [PRO09], [HAR04] indicates similar results regarding the ratio of the occupancies attendances. In order to increase the variety for office based electrical load profiles, Table 24 provides next to the profiles based on the metered data, 2 additional profile types.

Table 24: Mean value for the electrical loads O_1 taking into account office buildings, according to the metered data of [HDZ14b]. Additionally, O_2 and O_3 haven been created in order to provide a low and high load profile.

	O_1	O_2	O_3
$\sum P_{el}$ [W/m²]	2.344	1.8	3.5
$FEC_{el,i}$ [kWh/m²hr]	20.53	15.77	30.66

As given in Table 24, O_2 can be considered as low demand office building and O3 as high demand office building. According to [SIA06], P_{el}=6 W/m² and according to [ONO11], P_{el}=7.5 W/m², but both values include the internal gains due to the occupation. Since $P_{el(O2,O3)}$ given in Table 24 does not, the established scenario O_3 has a good match to the standards of [ONO11] and [SIA06]. However, O_2 and O_3 are based on the metered profile and thus, only the quantity changes, not the quality.

$$DF,occ,BC,i,k(t) = \frac{P,el,Oi(t) \times \frac{1}{\eta,E}}{GFA,BC} \tag{47}$$

$DF_{occ,BC,i,k(t)}$	*Density function for each time step (t) related to a certain building (BC), its occupation (i) and HVAC design with regards to E_t ... [W/m²]*
$P_{el,Oi(t)}$	*Electrical load due to the office occupation for each time step related to the real office occupancy ... [W]*

Analogues to the density function related to residential buildings, equation (47) derives the final density function taking into account the electrical loads related to office buildings. Furthermore, $\sum P_{el,Oi(t)}$ has been used as input data for the simulation engine as explained within Table 28.

In order to consider internal gains due to the occupation, the amount of attendant people related to the probabilistic of their attendance is important. Additionally, $n_{Att,O1(t)}$ varies every working day randomly within the bandwidth given within Figure 44. Thus, makes the qualitative profile more flexible. The results for the random attendance with regard to the upper and lower bandwidth of [PRO09] are given in the following.

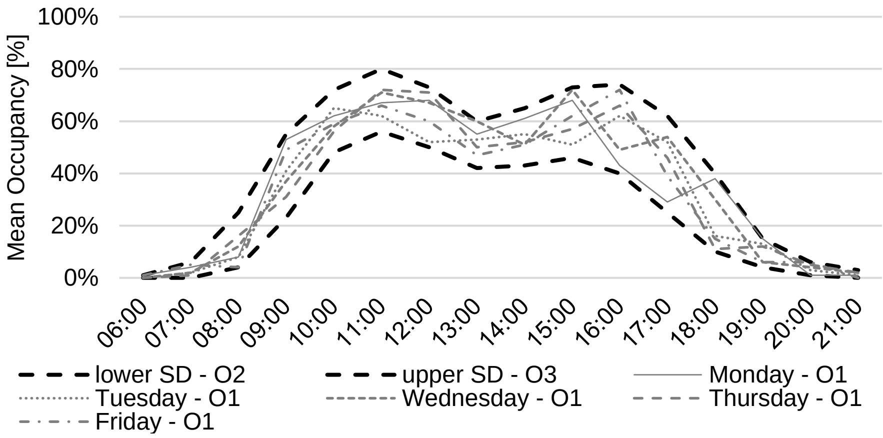

Figure 45: Attendances $n_{Att,i(t)}$ related to the occupation O_1 ($n_{Att,O1(t)}$), O_2 ($n_{Att,O2(t)}$) and O_3 ($n_{Att,O3(t)}$). While O1 relates to a random attendance within the given bandwidth of [PRO09], O_2 relates to the lower and O_3 to the upper bandwidth.

Therefore, $n_{Att,i(t)}$ applies to equation (48) and equation (49), given in the following.

$$P,gains,i(t) = n,Per \times n,Att,i(t) \times Pgain \qquad (48)$$

$P_{gains,i(t)}$	*Internal load due to attendant humans ... [W/m²]*
n_{Per}	*Amount of people related to one m² according to [HDZ14b],* $n_{Per}=1/14.64$ *... [Person/m²]*
$n_{Att,i(t)}$	*Attendance according to [PRO09] and Figure 44.* O_1 *relates to the random attendance given in Figure 45,* O_2 *to the lower bandwidth and* O_3 *to the upper bandwidth ... [%]*
P_{gain}	*Internal gain due to humans –* $P_{gain}=80$ *... [W/Person]*

Likewise $\sum P_{el,Oi(t)}$, $\sum P_{gains,i(t)}$ serve as input parameter for the simulation engine as explained within Table 28. In order to take advantage knowing the real attendances, the simulated cooling loads have been adjusted with $n_{Cool,i}$ as shown within Table 23 taking into account residential buildings. Thus, $Q_{Eb,cooling,BC,i(t)}$ is given in equation (49).

$$Q,Eb,cooling,BC,i(t) = Q,Eb,cooling,SIM,BC,i(t) \times n,Cool,i \qquad (49)$$

$Q_{Eb,cooling,BC,i,(t)}$	*Calculated cooling load for each time step (t) related to a certain building (BC) and occupation with regard to* E_b *... [W]*
$Q_{Eb,cooling,SIM,BC,i(t)}$	*Simulated cooling load for each time step (t) related to a certain building (BC) and occupation with regard to* E_b *... [W]*

According to equation (49), the simulation model for office buildings considers the cooling loads only if the thermal zone is attendant. Due to $Q_{Eb,cooling,BC,i(t)}$ relates to E_b, equation (16) given within chapter 3.3.2 balances at the level of E_t [IEA13].

However, in order to gain a deeper understanding regarding the occupation behavior within office buildings, research studies, as conducted in the course of the social differentiation given within chapter 3.4 as well as [HAU13] and [HAU16b], are absolutely necessary. Thus, energy load profiles for office buildings are likely related to literature instead of either to metered data or to results in the course of a comprehensive survey.

3.5 Load profile matrix

According to the previous chapters all input parameters and sub models have to be derived into a 3-dimensional load profile matrix, given in Figure 46.

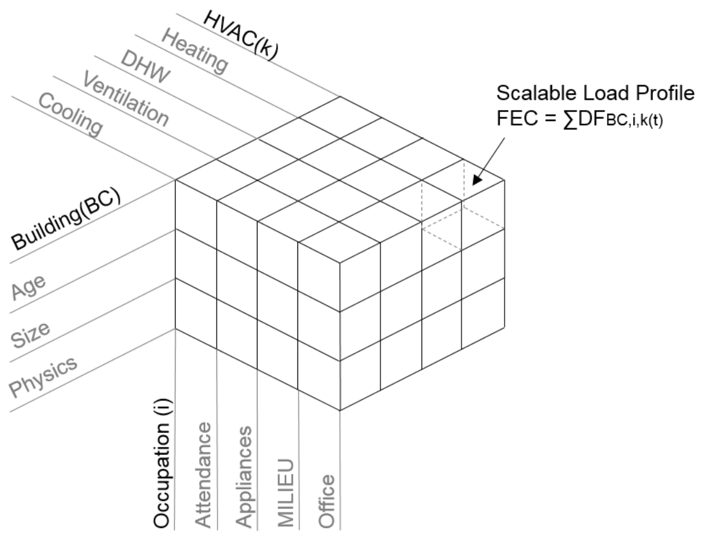

Figure 46: Visual of the 3-dimensional matrix addressing all scalable energy load profiles. This matrix is subject to the sub matrixes for buildings (BC), occupation (i) and HVAC design (k).

Figure 46 shows clearly that each energy load profile is related to a certain building (k), occupation (i) and HVAC design. Thus, sub matrixes have been created in order to point out the relation of each sub matrix to the 3-dimensional matrix given in Figure 46.

In accordance with the structure within chapter 3, the first sub matrix represents all variants in terms of buildings within the building cluster. With respect to the results of [ZIE15c] and in accordance with [MA11] as well as with WP1 [FRI16], the sub matrix for buildings has been created.

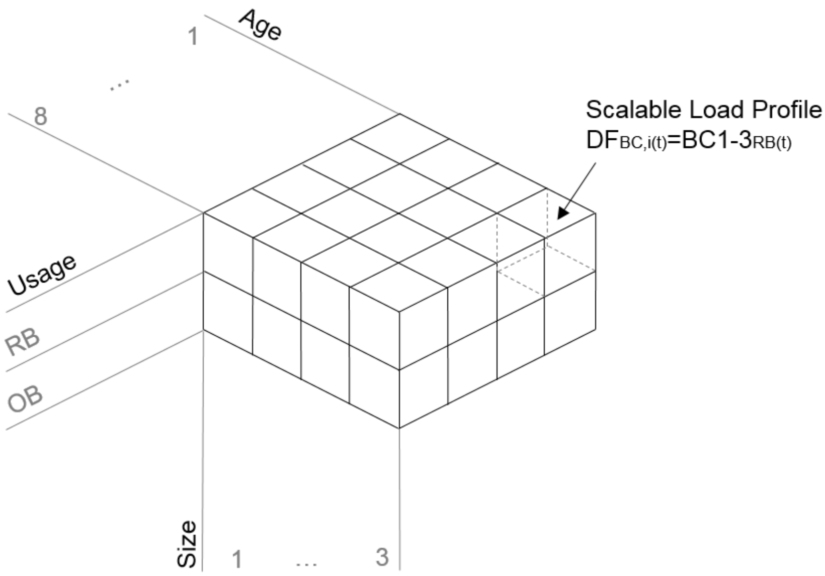

Figure 47: Sub matrix for all buildings within the building cluster, related to the 3-dimensional matrix given in Figure 46.

In accordance with chapter 3.2, Figure 47 indicates 8 different building clusters in terms of age and 3 different building clusters in terms of size. Furthermore, the building cluster is dedicated to either a residential building (RB) or to an office building (OB). This makes all buildings related to its occupancy (i).

The next sub matrix represents all variants for all possible HVAC design combinations.

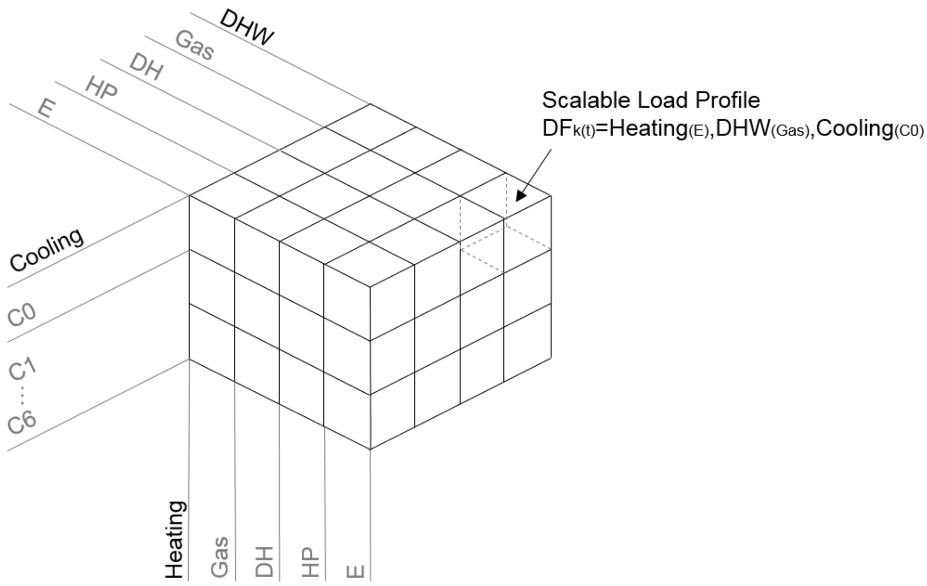

Figure 48: Sub matrix for all HVAC designs, related to the 3-dimensional matrix given in Figure 46.

In order to fulfill all scenario requirements within the URBEM, a various of heating, DHW and cooling options have been created. In accordance with chapter 3.3, Figure 48 indicates 9 different heating systems, 6 different DHW systems and 7 different cooling systems. Except for the DHW and its distribution, the HVAC design is not directly related to the building cluster. One of the key elements within this thesis is a detailed understanding regarding the occupancy, whether the building is a residential building (milieu based approach) or it is an office building.

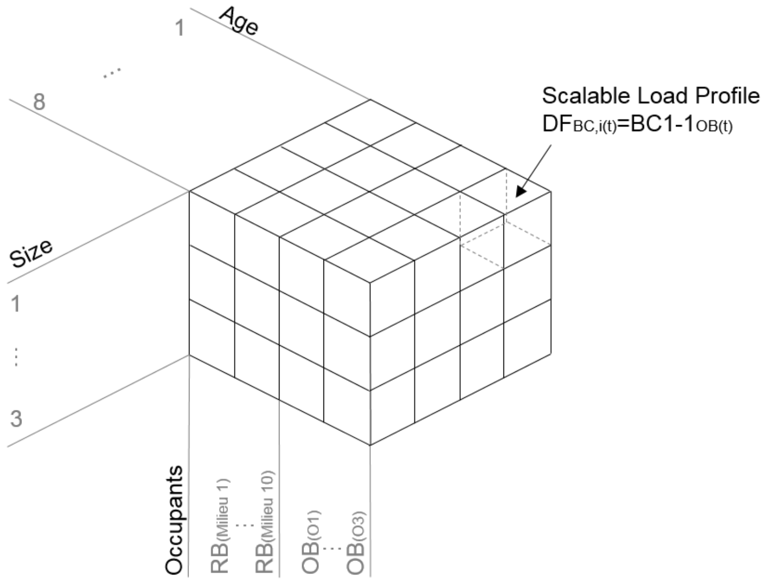

Figure 49: Sub matrix for all occupants, related to the 3-dimensional matrix given Figure 46.

Due to the occupancy comes along with a various of input parameters for the building simulation (see chapter 3.4), the occupant's behavior is directly related to the building cluster.

Derived from all matrixes above, the number of all possible scalable energy load profile options is given in Table 25. Due to the occupancy is directly related to the building cluster, the number for all scalable energy load profiles has to be separated into residential buildings (RB) and office buildings (OB).

Table 25: Theoretical number of all scalable energy load profile options within this thesis.

	Building cluster(BC)		HVAC designs(k)		Occupation(i)		Number of possible profiles
RB	21	x	378	x	10	=	79 380
OB	21	x	378	x	3	=	23 814

Table 25 outlines the possible number of scalable energy load profiles within this thesis. However, this is a theoretical number. Due to uncertainties within the URBEM scenarios as well as technical restrictions, this thesis focuses only on useful and appropriate combinations. Thus, the maximum number of different HVAC design options is limited with 12 options for residential buildings and 16 options for office buildings. Thus, the number of all possible scalable profiles decreases to 2520 profiles for residential buildings and 1008 profiles for office buildings.

Table 26: Effective number regarding all scalable energy load profile options within this thesis.

	Building cluster(BC)		HVAC designs(k)		Occupation(i)		Number of possible profiles
RB	21	x	12	x	10	=	2 520
OB	21	x	16	x	3	=	1 008

Summarizing the setup of all matrixes, the final matrix for energy load profiles can be derived and is given in Figure 50.

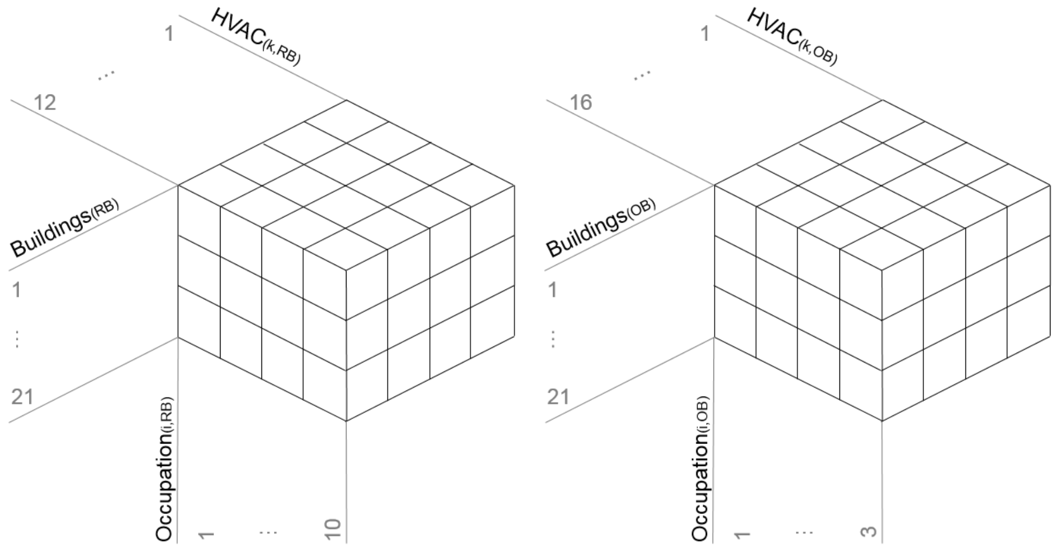

Figure 50: Final visual of the 3-dimensional matrix for all scalable energy load profiles taking into account residential buildings (on the left) and office buildings (on the right).

According to the 3-dimensional matrix given in Figure 46 and related to all sub matrixes, Table 27 points out the naming procedure for all density function. As outlined in Table 1, all density functions are subject of an unified naming procedure in order to ensure the data handling within the URBEM simulation environment.

Table 27: Naming procedure for all scalable energy load profiles with respect to the 3-dimensional matrix given in Figure 46.

Example DF: 8-3_RB_DH_FH_E_S0_C6_3-ETA								
Building[1]			HVAC design[2]					Occupation[3]
Age	Size	Occupancy	Heating	Distribution	DHW	Solar[4]	Cooling	Occupants
1	1	RB	G	FH	G	S0	C0	1-KON
2	2	OB	DH	RH	DH	S1	C1	2-TRA
4	3		HP-1	Tabs[5]	HP-A		C2	3-ETA
5			HP-2		HP-G		C3	4-PER
6			HP-3		HP-W		C4	5-PMA
7			HP-4		E		C5	6-DIG
8			HP-5				C6	7-BÜM
			HP-6					8-PRA
			E					9-KBA
								10-HED
								O1/O2/O3

[1]…according to chapter 3.2; [2]…according to chapter 3.3; [3]…according to chapter 3.4; [4,5]…not yet implemented, see chapter 6

Due to the consistent naming procedure both, the data management within the UBREM simulation environment and the initializing process regarding the URBEM scenarios is as simple as possible.

3.6 Simulation setup

This chapter is dedicated to the setup of the simulation environment within this thesis. Furthermore, the workflow starting with the input parameters and ending with the output parameters given in Table 1, will be outlined. In accordance with all other work packages within the URBEM simulation environment, all scalable energy load profiles are based on a one-hour time step. In order to generate all scalable energy profiles a pre-simulation sequence has been established and is given in chapter 3.6.3. Beside the given building physics parameters for all building models within the building cluster (Table 3), all significant geometrical data are given in Table 35 within chapter 7.5.

3.6.1 Building simulation model

As mentioned in chapter 2, there are several building simulation engines which are common and well disseminated. In order to fulfill the aims within this thesis, the buildings simulation engine has to be expandable, modular, capable regarding further linking processes as well as robust. Thus, as briefly mentioned within chapter 2, the simulation engine of [GLA14] has been used. This simulation engine has been used and validated within [HDZ14a]. [GLA14] and [HDZ14a] describe the RC (residence capacity) multi zone simulation engine and the algorithm using an ordinary differential equation solver for stiff or non-stiff systems. The development of this buildings simulation engine is an ongoing process within the TU Wien and thus, all technical upgrades within this thesis ensure a sustainable and continuous development process. The significant contributions of this thesis onto that simulation engine are:

- the implementation of different HVAC designs according to chapter 3.3 in order to balance at the level of E_t [IEA13],
- a new automated input data set in the course of the milieu based approach according to chapter 3.4,
- as well as the method to derive density functions in order to create scalable energy load profiles.

The applying architecture and simulation setup are given in Figure 51. It also underlines its modular design. Except of the simulation engine of [GLA14], all in- and outputs as well as the sub models regarding the HVAC design are subject of this thesis.

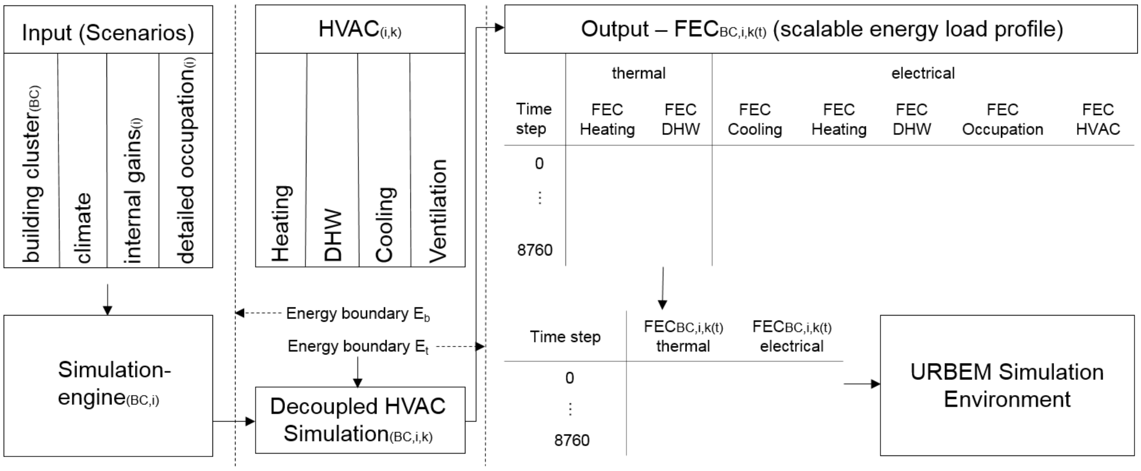

Figure 51: General architecture of the simulation setup with respect to its modular design. The visual underlines the workflow in order to create scalable energy load profiles in terms of the predicted final energy consumption taking into account thermal and electrical energy.

Figure 51 represent the workflow in order to create scalable energy profiles for the URBEM simulation environment with respect to the building cluster, its occupation and HVAC design. Moreover, each simulation model is dedicated to a certain building (e.g. BC1-3 or BC6-3) in terms of a single zone building model, due to the high numbers of uncertainties considering all buildings within a city. With respect to the scenario parameters the simulation engine gets fed with several input parameters such as detailed parameters related to the building cluster as well as internal gains and loads based on chapter 3.4. Due to its modular design before and after the simulation engine, the simulation setup enables a continuous upgrade process. Further research efforts in order to maintain a sustainable development of that simulation engine are addressed within chapter 6.

3.6.2 Input parameters

Besides the input parameters given in chapter 3, the UBREM simulation environment uses a certain climate data set. In order to do so, the climate data set given in [KRA14] has been used within all work packages. This set of climate data consists of air temperature [°C], relative humidity [rel.%], as well as the horizontal diffuse and direct solar radiation [W/m²]. Due to all windows for every building within the building cluster are vertical, the horizontal solar radiation gets transformed to the vertical solar radiation using the model of [VDI12]. The model of [VDI12] has been used and comprehensively described within the work of [HDZ14a] and [HAN14].

Table 28: Input parameters for the simulation engine related to the climate and occupation.

	Climate		Occupation				
	Ambient air temperature $\vartheta_A(t)$	Solar radiation $\sum I_{g,ver}(t)$	Internal gains $\sum P_{gains,i}(t)$	Internal loads $\sum P_{el,i}(t)$	DHW draw off $\sum m_{i,DHW}(t)$	Windows pWindow,i(t) 0 … 1[1]	Cooling ncool,i(t) 0 … 1[2]
0	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
8760	⋮	⋮	⋮	⋮	⋮	⋮	⋮

[1]… 0 - Window closed, 1 - Window opened; [2]… 0 – cooling off, 1 – cooling on (see chapter 3.4)

Table 28 represents all dynamic input parameters for the simulation engine. Due to the climate data remain constant within the URBEM simulation environment, these data set can be changed in the course of further climate scenarios. However, the data set related to the occupation is subject to change for each considered occupation scenario (e.g. milieu 1 or milieu 7) and building cluster.

3.6.3 Simulation sequence

Due to each building within the building cluster is related to a certain simulation model, 42 building models have been created, 21 related to residential buildings and 21 related to office buildings. As shown within Table 26 and Figure 50, 3528 scalable load profiles have been created. Thus, 273 pre-simulation runs have been conducted in order to create those profiles. For the purpose to run all pre-simulations automatically, a simply calibration procedure has been developed and is given at Figure 52.

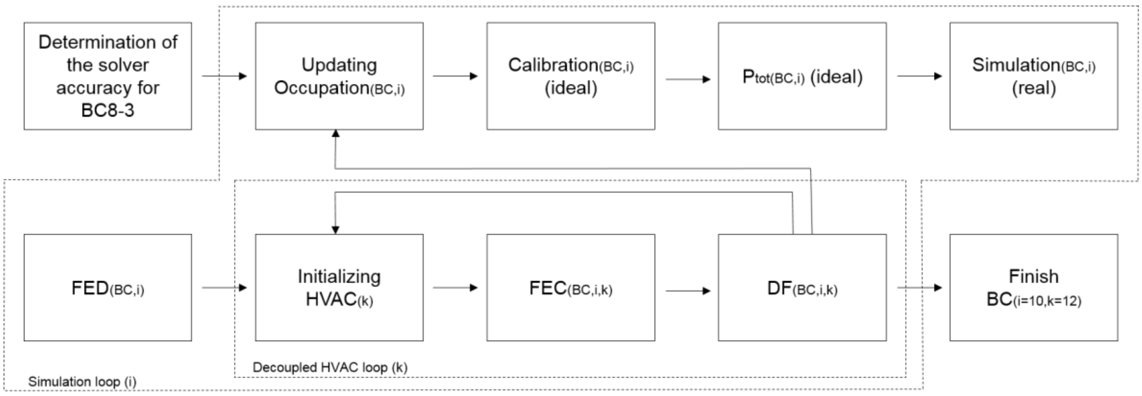

Figure 52: Simulation sequence for one residential building (e.g. BC8-3) with respect to the calibration, simulation loop as well as to the decoupled HAVC loop.

In order to maintain the desired indoor temperature z1_tAir$_{(i)}$, $P_{tot(BC,i)}$ has to be determined by running an ideal simulation. In order to determine $P_{tot(BC,i)}$, the desired indoor temperature z1_tAir$_{(i)}$ remains constant through the entire year (ideal simulation run). The real simulation run uses $P_{tot(BC,i)}$ as heating capacity in combination with a 2-step controller, in order to avoid a drop of the desired indoor temperature z1_tAir$_{(i)}$ at the real simulation run. $P_{tot(BC,i)}$ as well as the indoor temperature bandwidth is given in Figure 53.

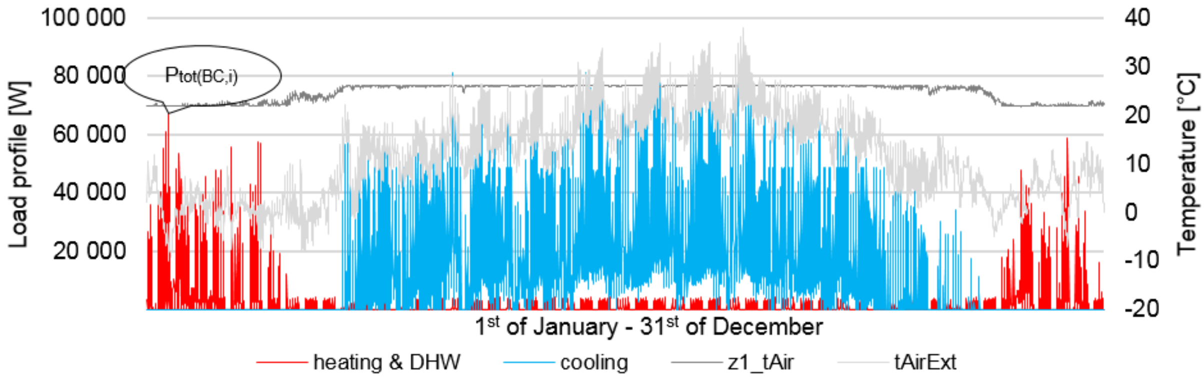

Figure 53: Simulation calibration using the zone temperature z1_tAir on the example of office building BC8-3 with regards to the occupation scenario O3. The indoor temperature z1_tAir ranges from the minimum temperature z1_tAir(i) and the maximum temperature of 26°C, using a 2-step controller. Due to the use of $P_{tot(BC,i)}$ instead of P_{tot}, the indoor temperature never drops among the desired indoor temperature z1_tAir(i).

Figure 53 shows $P_{tot(BC,i)}$ and the bandwidth of the indoor temperature due to the 2-step controller. Without that calibration procedure, P_{tot} remains constant regardless of the occupation scenario and thus, the heating capacity may not maintain the minimum indoor temperature z1_tAir(i). Moreover, each simulation model has to be set up with an appropriate solver accuracy [GLA14]. The accuracy of the solver is mainly related to the capacity of the building and its capacity of the heating system. Thus, this process has been done in advance for each building model individually. Figure 54 addresses the results for the indoor temperature without an appropriate solver accuracy and no calibration run for P_{tot}.

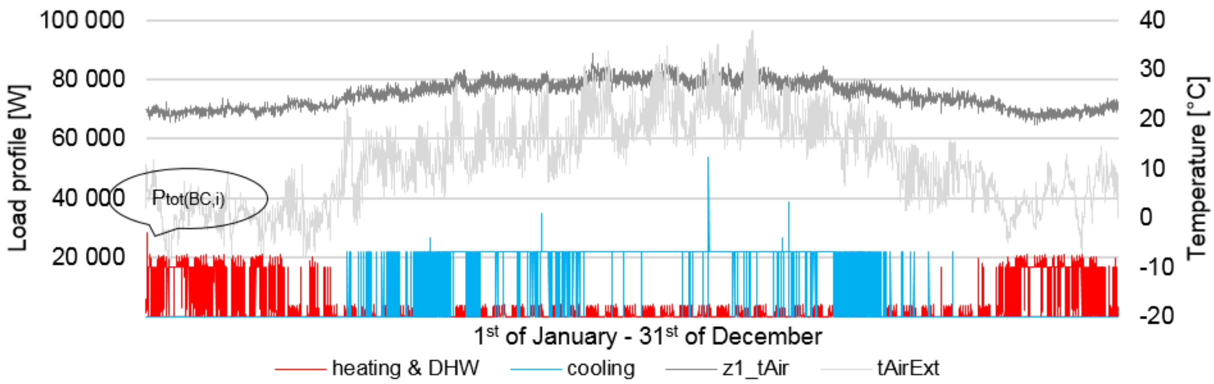

Figure 54: Simulation results with an inappropriate solver accuracy and without the calibration procedure in order to determine $P_{tot(BC,i)}$ instead of P_{tot}. The solver and the 2-step controller is not capable to maintain the minimum and maximum indoor temperature (z1_tAir < z1_tAir(i)). Furthermore, load peaks can't be addressed – see $P_{tot(BC,i)}$ at Figure 53 and P_{tot} at this plot.

Figure 53 and Figure 54 underlines the impact of the solver accuracy and calibration procedure on the indoor temperature. The procedure in order to determine $DF_{(BC,i,k)}$ is given at Figure 52 and can be considered as an elaborating and comprehensive process. However, that process enables an automated generation of scalable load profiles when the calibration of each simulation model is finished and thus, each simulation model can be used within the URBEM simulation environment independently.

3.6.4 Scalable energy load profiles

As mentioned within chapter 3.1, all scalable energy load profiles are related on the predicted final energy consumption FEC. While the previous chapter 3.6.3 addresses the pre-simulation sequence in order to determine the density function $DF_{(BC,i,k)}$, this chapter is focusing on the equations. In order to distinguish the different energy consumption profiles, such as for heating, cooling, DHW or electricity, the FEC is divided into 7 FEC profile types according to Figure 51. The profiles for the heating and cooling loads are written as density functions (e.g. $DF_{heating,BC,i,k(t)}$), regardless if it's either thermal or electrical. However, the specific profiles for the DHW as well as the occupation and HVAC based electricity consumption, are related to the gross floor area (e.g. $DF_{DHW,i,k(t)}$ or $DF_{el,i,k(t)}$).

$$\begin{aligned} FECth, BC, i, k(t) &= DF, heating, th, BC, i, k(t) \times GFA(BC, i, A) \times FEDth, heating(BC, A) \\ &+ DF, DHW, th, BC, i, k \times GFA(BC, i, A) \end{aligned} \quad (50)$$

$$\begin{aligned} FECel, BC, i, k(t) &= DF, heating, el, BC, i, k(t) \times GFA(BC, A) \times FEDth, heating(BC, A) \\ &+ DF, DHW, el, BC, i, k(t) \times GFA(BC, A) + DF, cooling, BC, i, k(t) \\ &\times GFA(BC, A) \times FEDth, cooling(BC, A) + DF, occ, BC, k, i(t) \times GFA(BC, A) \\ &+ DF, aux, BC, k, i(t) \times GFA(BC, A) \end{aligned} \quad (51)$$

$$FEC, BC, i, k(t) = FECth, BC, i, k(t) + FECel, BC, i, k(t) \quad (52)$$

DF	*Density function related to the building cluster (BC), occupation (i) and HVAC design (k) … [W/kWh]*
GFA	*Gross floor area related to BC, occupation and URBEM Scenarios (A) … [m²]*
$FED_{(BC,A)}$	*Final energy demand related to the UBREM Scenarios (A) with regards to heating and cooling – $FED_{heating(A)}$, $FED_{cooling(A)}$ according to [FRI16] … [kWh/m²yr]*
$FEC_{BC,i,k(t)}$	*Predicted final energy consumption related to the building cluster (BC), its occupation (i) and HVAC design (k) … [kWh]*

Equation (50) and (51) are representing the scalable energy load profile. Both equations are addressing either the derived FEC_{th} or FEC_{el} related to a specific building within the building cluster (BC), to its occupation (i), to a certain HVAC design and to the time sensitive profile (t). Due to the energy balancing according to [IEA13] and chapter 3.1, the total of FEC_{th} and FEC_{el} is not relevant, however, equation (52) addresses the predicted final energy consumption regardless of the energy type.

3.6.5 Simulation results

The method of using scalable load profiles in order to provide time sensitive and validated load profiles to the URBEM simulation environment is subject on pre-simulation results for every building category. The advantage of this method is to avoid time intensive and detailed building simulation tools, without losing detailed load profile characteristics as well as the impact of different building physics parameters. While the results regarding the capability of this method are given in chapter 5, this chapter focuses on individual simulation results for each building within the building cluster.

Table 29: Summary for the predicted annual final energy consumption regarding all residential buildings within the building cluster, in order to address the quantitative differences. Due to the balancing at the level of E_t of [IEA13], the energy conversion ratio for a district heating system is included. All values in terms of thermal and electrical energy consumption are related to milieu 1 (i = 1).

kWh/m²yr	FEC heating	FEC DHW	FECel MIL1	FEC HVAC	FEC thermal	FEC elec.
BC1-1	350.80	24.26	29.96	4.35	375.05	34.30
BC1-2	145.67	34.09	29.96	1.99	179.76	31.95
BC1-3	134.48	28.56	29.96	1.85	163.04	31.80
BC2-1	235.66	19.35	29.96	3.32	255.01	33.27
BC2-2	118.74	29.89	29.96	1.74	148.63	31.70
BC2-3	110.69	27.31	29.96	1.60	138.00	31.56
BC4-1	261.02	15.81	29.96	3.43	276.83	33.39
BC4-2	129.57	20.99	29.96	1.75	150.55	31.71
BC4-3	113.64	21.02	29.96	1.59	134.65	31.55
BC6-1	131.85	15.55	29.96	1.8	147.40	31.76
BC6-2	99.26	21.47	29.96	1.49	120.73	31.45
BC6-3	90.48	19.75	29.96	1.37	110.23	31.32
BC8-1	50.24	15.22	29.96	1.17	65.46	31.12
BC8-2	26.83	19.66	29.96	0.67	46.49	30.63
BC8-3	23.99	18.85	29.96	0.67	42.85	30.62

By comparing all predicted energy consumption values, the importance to distinguish between different building ages and sizes becomes very clear. Even all values are specific [kWh/m²yr], the results underline the importance of a detailed understanding regarding the specific energy consumption for each building with respect to its size and age. Analogues to the results for all residential buildings, the results related to office buildings are given in Table 30.

Table 30: Summary for the predicted annual final energy consumption regarding all office buildings within the building cluster, in order to address the quantitative differences. Due to the balancing at the level of Et of [IEA13], the energy conversion ratio for a district heating system and for the cooling system is included. All values in terms of thermal and electrical energy consumption are related to B1. The energy efforts for the DHW is included within the FED electricity.

kWh/m²yr	FEC heating	FECel O1	FEC Cooling	FEC HVAC	FEC thermal	FEC elec.
BC1-1	217.78	21.54	5.95	4.37	217.78	33.33
BC1-2	137.54	21.54	2.07	2.06	137.54	27.13
BC1-3	123.17	21.54	1.83	1.46	123.17	26.67
BC2-1	197.14	21.54	6.42	4.38	197.14	33.81
BC2-2	129.14	21.54	2.19	2.03	129.14	27.22
BC2-3	114.44	21.54	1.33	1.57	114.44	25.89
BC4-1	173.02	21.54	6.29	4.10	173.02	33.39
BC4-2	110.53	21.54	2.19	1.84	110.53	27.03
BC4-3	96.69	21.54	1.33	1.39	96.69	25.72
BC6-1	116.78	21.54	5.32	3.23	116.78	31.55
BC6-2	68.68	21.54	1.93	1.35	68.68	26.27
BC6-3	62.63	21.54	1.72	1.20	62.63	25.93
BC8-1	8.10	21.54	5.62	6.63	8.10	35.25
BC8-2	2.58	21.54	2.59	4.91	2.58	30.50
BC8-3	1.80	21.54	2.23	4.75	1.80	29.99

The results and their interpretation considering office building are similar to the residential buildings. It becomes also clear, to distinguish between residential and office buildings is absolutely necessary. Not only in terms of the energy load profile characteristics, but also in terms of the absolute predicted energy consumption. Due to this method is using specific energy consumption values in order to make them scalable, the importance of those findings are even more significant and impacts the URBEM scenarios given in [FRI16].

As this method is taking advantage of a milieu based approach, a detailed understanding regarding the general energy behavior could be gathered within this thesis (see chapter 3.4). Therefore, all results regarding the final energy consumption of Table 29 and Table 30 are subject to an occupation based bandwidth. In order to address that specific issue, the results for the bandwidth considering the predicted final energy consumption for heating, domestic hot water as well as for the electricity within residential buildings are given in Table 31.

Table 31: Simulated bandwidth related to the overall mean value of the final energy consumption regarding the heating, domestic hot water and electricity consumption in the course of the social differentiation (i = 1…10) according to the raw data of [HAU16b] and the results of chapter 3.

	BC8-3	BC8-1
FEC Heating	-12% to 14%	-11% to 11%
FEC DHW	-13% to 7%	-21% to 14%
FEC Electricity	-12% to 12%	-14% to 12%

The key findings of Table 31 are, that the $FEC_{Heating}$ and $FEC_{Electricity}$ bandwidths are not related to the building cluster. The range of the deviation is more or less constant. However, the bandwidth for the domestic hot water consumption is varying. This is due to the fact that all multifamily buildings are equipped with a circulation pipe and thus, both the heat losses and the predicted final energy consumption increases. Due to the increased consumption, which is not related to the occupation (approx. 50% according to Table 32), the FEC_{DHW} bandwidth addressing buildings with a circulation pipe is approximately half as much.

4 Validation

This chapter emphasizes the most important validation results within this thesis. All results are corresponding with the energy balancing method given in chapter 3.1 and thus, the results can be considered as predicted energy consumption instead of energy demand according to E_b of [IEA13]. All further validation results are related to the simulation results using the consumption model given in chapter 3.6. The validation results regarding the density function are given in [ZIE15a] and [ZIE15c].

4.1 Validation of the consumption model

The validation procedures within this chapter are focusing on sub criteria's such as the heating consumption, use of domestic hot water as well as on the electricity consumption related to the HVAC design and occupancy. Therefore, this chapter can be considered as a bottom up approach in order to validate the results.

4.1.1 Single family case study building

According to the results given in chapter 3.6.5 the buildings size and its age are crucial in order to achieve accurate results by using density functions. Therefore, the validation procedure addresses the comparison of buildings within a certain building cluster. Based on data from [LED16] and [NEU15], a single family house has been simulated in order to compare the results with metered data of 4 identical buildings. Due to all buildings are identical in construction, the key facts regarding the building characteristics for all buildings are given in Table 32 and serve as input data for the simulation model.

Table 32: Data collection of the main parameters related to a single family house (BC8-1) in the course of the validation procedure, in order to simulate and compare the results.

Description	Data
GFA	101.99 m²
Compactness	0.98
Length / width / height	10.92 / 4.67 / 5.4 m
Window / wall ratio	0.19
U_{Window}	1.2 W/m²K
g_{Window}	0.5
U_{Wall}	0.2 W/m²K
$U_{Ceiling}$	0.21 W/m²K
BC	8-1

These houses are located in Vienna and each can be considered as a typically single family house. Firstly, the great data collection of all buildings enables an accurate validation for the final gas and electricity consumption. Secondly, due to the fact that all 4 buildings are identical in construction, the results are highly valuable in order to analyze the results with respect to the milieu-based approach. Those facts, make all 4 buildings to valuable case study buildings in order to validate with.

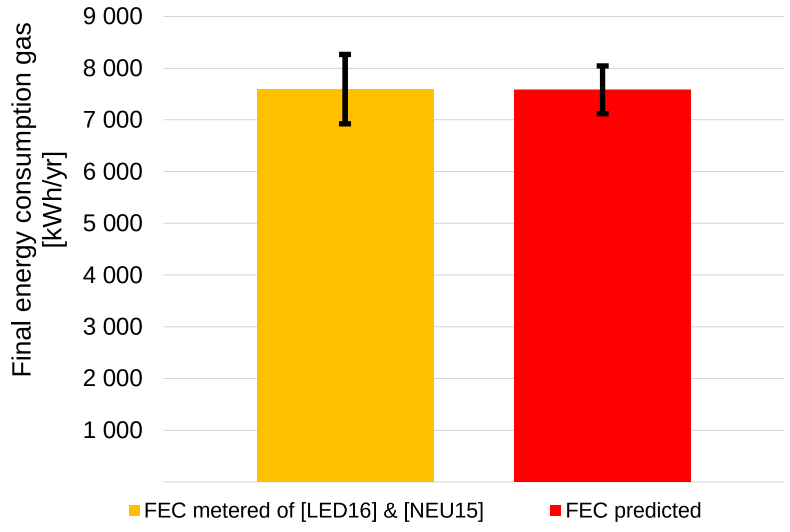

Figure 55: Comparison of the annual gas consumption (with regard to E_t of [IEA13] and FEC) including the standard deviation for all single family case study buildings and the simulation results in order to generate validated density functions for BC8-1.

Figure 55 highlights the results for the metered final gas consumption and the predicted final energy consumption based on the simulation with respect to E_t according to [IEA13]. The standard deviation for both results emphasizes the deviation due to the occupancy. While the milieus for the metered data are unknown, the standard deviation for the simulation results emphasize the impact of different milieus onto the predicted final energy consumption for a single family house. While the results for the annual gas consumption given in Figure 55 have an accurate match, those for the electricity consumption given in Figure 56 are showing slight differences.

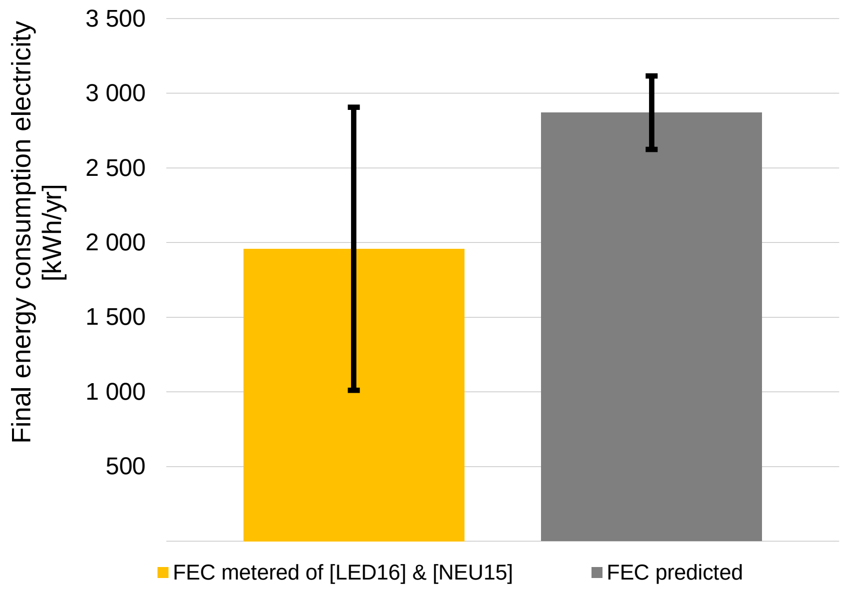

Figure 56: Comparison of the annual electricity consumption (with regard to E_t of [IEA13] and FEC) including the standard deviation for all single family case study buildings and the simulation results.

The mean value regarding the simulated electricity consumption performs 800 kWh/yr higher than the metered data. The reason for that mismatch may lie on the uncommon low electricity consumption of 2 out of 4 buildings compared with statistic data of [ECON16]. As mentioned, the milieus for those 4 buildings are not known and thus, a detailed understanding regarding the differentiation of milieus and time sensitive metered data related to the electricity consumption is absolutely necessary for further research. The results within chapter 3 emphasize the importance of specific values rather than absolute values in order to increase the reliability and consistency using data in the course of a questionnaires. Figure 57 merges the results for the specific electricity consumption related to the number of persons per household. The match for both, 2 and 3 persons per household may give an idea regarding the real occupancy within that single family case study building.

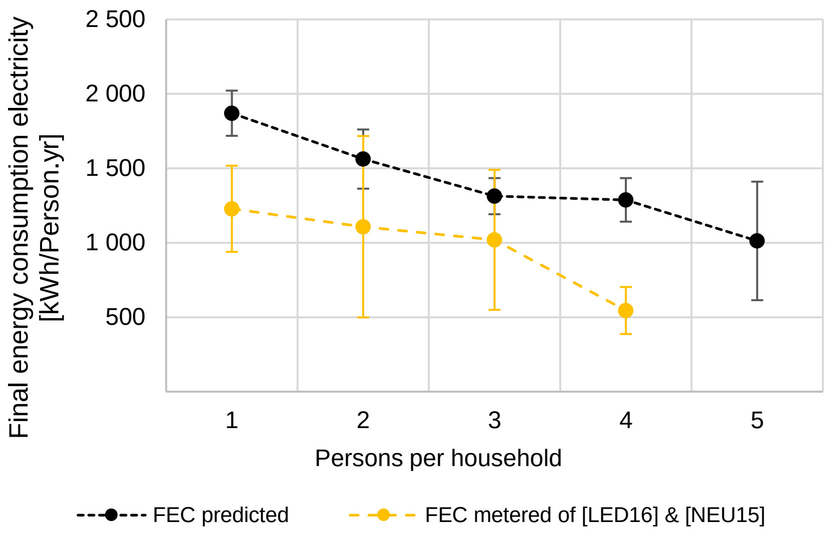

Figure 57: Comparison of the annual electricity consumption per person (with regard to E_t of [IEA13] and FEC) with respect to the occupation per household, including the standard deviation for the single family case study building and the calculation results for BC8-1.

4.1.2 Multifamily case study building

In order to validate buildings related to the category of building size 3 data from [MAS14] have been used to compare with. This building represents a common multifamily house in the center of Vienna. Analogues to the single family case study building, disaggregated data in order to validate sub criteria are available as metered data and as raw data in the course of the design process.

Table 33: Data collection of the main parameters of a multifamily house (BC8-3) in the course of the validation procedure, in order to simulate and compare the results.

Description	Data
GFA	5 400 m²
Compactness	0.23
Length / width / height	40 / 22.5 / 22 m
Window / wall ratio	0.42
U_{Window}	1.2 W/m²K
g_{Window}	0.5
U_{Wall}	0.147 W/m²K
$U_{Ceiling}$	0.186 W/m²K
BC	8-3

The data of [MAS14] enable a validation procedure at the level of the annual heating consumption, the annual domestic hot water consumption as well as the annual electricity consumption related to both, HVAC and occupancy. Furthermore, metered data are available on the level of the final thermal and electricity consumption. [MAS14] addresses the differences of 2 methods, so called standard and tailored and thus, the 2 bars on the left given in Figure 58 represent the validation data to compare with.

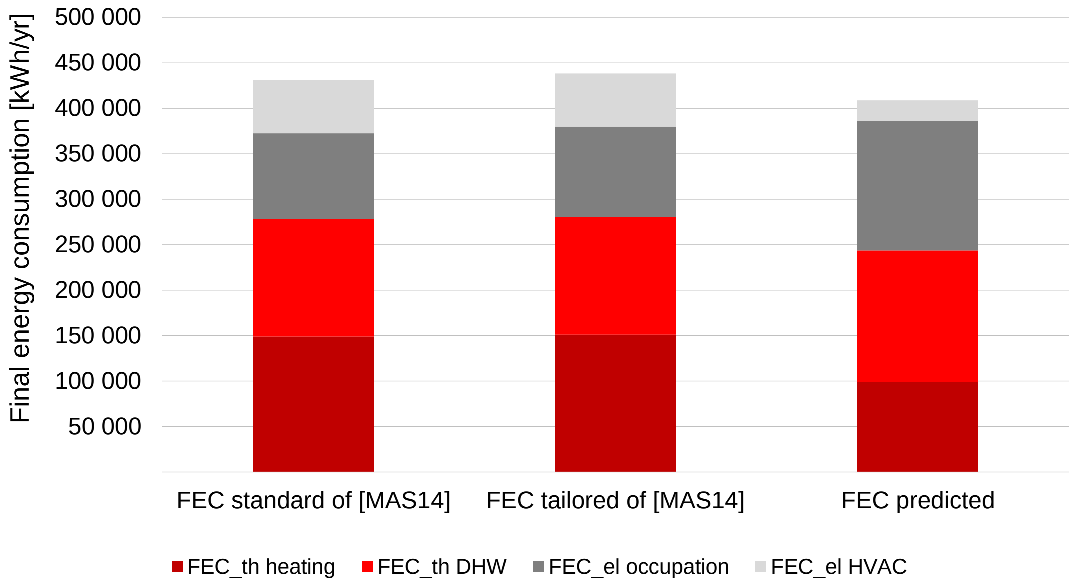

Figure 58: Comparison of the calculated annual energy consumption [MAS14] for the multifamily case study building and the simulation results with focus on the final energy consumption for heating, domestic hot water as well as the final electricity consumption related to the occupation and HVAC for BC8-3 (with regard to E_t of [IEA13] and FEC).

As this case study building for multifamily houses is taking advantage of an air heat recovery heat pump for domestic water generation and the method within this thesis does not, balancing on the level of E_t according to [IEA13] makes it difficult to compare with. The impact of that specific technology can be seen on the lower energy consumption for domestic hot water and the higher electricity consumption related to the HVAC given in Figure 58. That specific technology hasn't been considered within this research and thus, that specific shift from thermal energy to electrical energy can't be addressed. However, the comparison given in Figure 59 for the metered consumption shows a quite good match, even the previously mentioned shift is slightly visible.

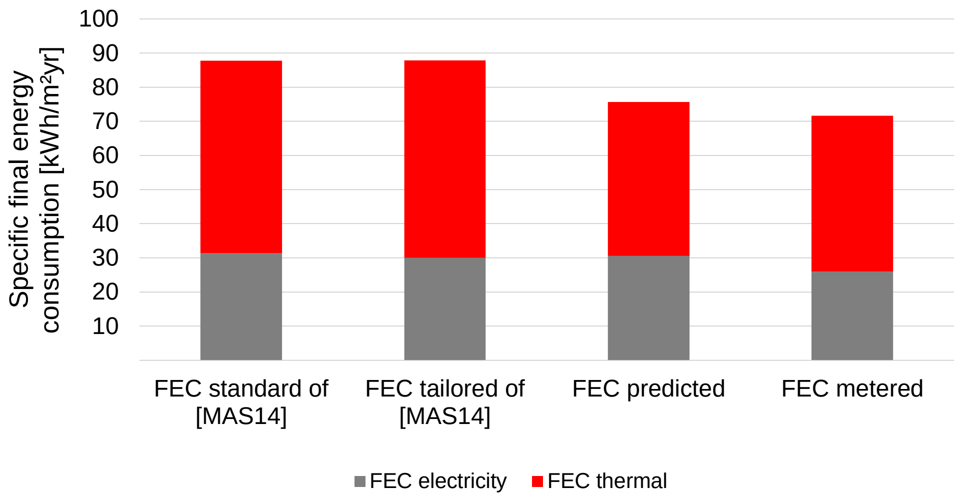

Figure 59: Comparison of the specific annual energy consumption (with regard to E_t of [IEA13] and FEC) for the multifamily case study building (both calculated and metered) and the simulation results with focus on the overall thermal and electrical consumption for BC 8-3.

Additionally, the domestic hot water demand related to the number of occupants is well known for that multifamily house. According to the results of the questionnaires regarding the milieu based domestic hot water consumption, the specific consumption can be compared with metered data of that multifamily case study building. Figure 60 highlights the differences including the consideration of the standard deviation. It becomes clear, that raw data from questionnaires, which are related to E_b of [IEA13]), are inappropriate to use them directly in order to validate the predicted domestic hot water demand with metered data which are related to E_t of [IEA13] and FEC.

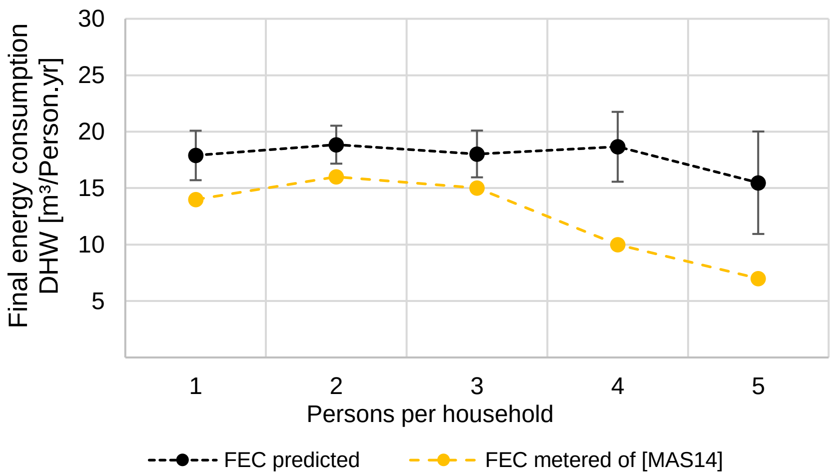

Figure 60: Calculated mean values of the domestic hot water demand based on the questionnaires compared to metered data of the multifamily case study building.

Therefore, the results for the milieu based predicted domestic hot water consumption have been used as input parameter for the building simulation. This enables not only the calculation of the predicted consumption, but also the consideration of specific parameters such as heat losses, distribution losses as well as the modelling of the DHW circulation pipe. Based on the level of E_t

according [IEA13], the validation results for the predicted energy consumption related to the DHW are given in Figure 61.

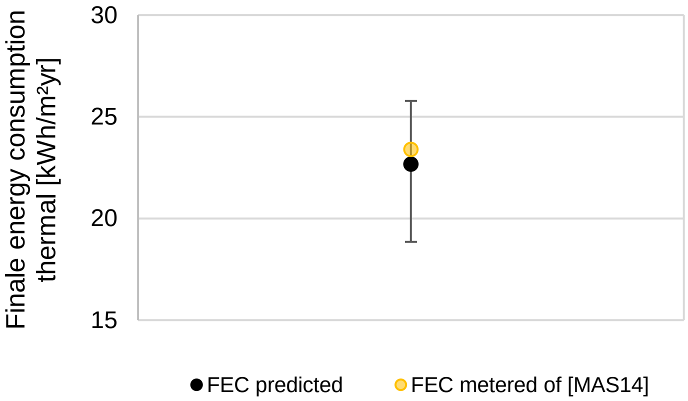

Figure 61: Predicted thermal energy consumption (with regard to E_t of [IEA13] and FEC) for all milieus based on the simulation results for the DHW system for BC8-3, compared with metered data of the multifamily case study building.

Due to the fact that the heat recovery within that case study building has been installed later, metered data for one year without that specific impact are available and thus, makes this data appropriate in order to validate with. The mean value shows an almost perfect match to the metered data. In the course of the simulation for all 10 milieus the range for the predicted thermal consumption for the DHW starts at 18.85 kWh/m²yr and ends up at 25.78 kWh/m²yr. The range of those results emphasize the importance of an enhanced understanding regarding the occupation. In accordance with the previous results for the predicted heating and DHW consumption, the results for the predicted electricity consumption are given in Figure 62.

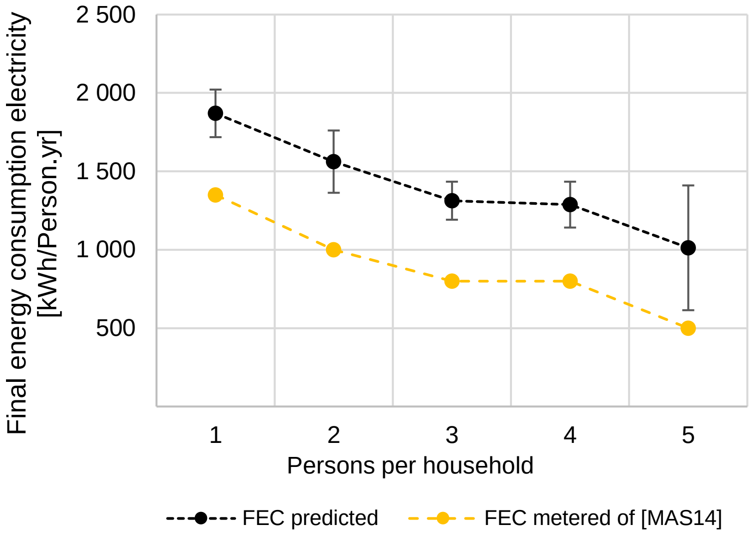

Figure 62: Comparison of the annual electricity demand per person with respect to the occupation per household, including the standard deviation for the single family case study building and the calculation results for BC8-3 of [MAS14].

Likewise the previous results regarding the comparison of calculated data of [MAS14] with the calculation result in the course of the questionnaires, raw data regarding the predicted electricity consumption are not appropriated neither. Analogues to the previous procedure those data have been used as input parameter for the building simulation. The impact of using specific data instead of absolute data given in Figure 62, can be seen on Figure 63.

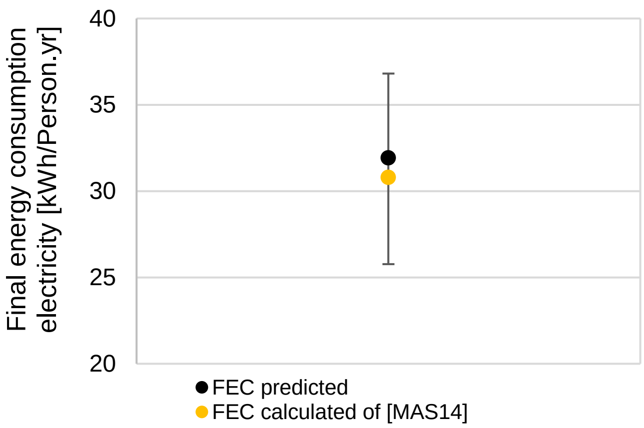

Figure 63: Predicted electricity consumption (with regard to E_t of [IEA13] and FEC) for all milieus based on the simulation results for BC8-3, compared with calculated data of the multifamily case study building according to [MAS14].

The results are showing an accurate match with the validation data only after running a dynamic building simulation model for all milieus.

4.1.3 Conclusions regarding the validation of the consumption model

The results are emphasizing not only the impact of different occupations scenarios in terms of a milieu based approach, but also points out the limits of using raw data in the course of a questionnaires. According to the results of Figure 57, Figure 60 and Figure 62, raw data are only appropriate for qualitative analyses instead of quantitative. This attributes to the fact that all raw data are absolute values, which means there is no context to the reference area. Furthermore, raw data from the questionnaires relates to E_b instead of E_t according to [IEA13]. Thus, the building simulation is taking the input parameters only as specific values related to the reference area. Moreover, the higher the aggregation and consistency of data (e.g. bigger buildings or more data) the more accurate the results regarding the predicted consumption. Figure 56 underlines the high diversification by considering only 1 or 2 buildings. Additionally, almost all results (e.g. Figure 55, Figure 56, Figure 61 and Figure 63) have shown the wide range when considering a milieu based approach, although the mean values have shown an accurate match. The method of validating the consumption model at the level of sub criteria has shown both, advantages and disadvantages. The major advantage is to validate regardless of time sensitive metered data and to focus on every available data set as long a sufficient diversification in terms of building age and its size is ensured. As disadvantage can be considered different approaches in terms of energy balancing (e.g. E_b and E_t) in order to validate on the same energy balancing level. The simulation model given in chapter 3.6 has a great accordance to the metered data within this chapter. Thus, the simulation model has been used in order to generate scalable energy load profiles according to the equations within chapter 3.6.4.

4.2 Validation of the electrical load profiles

As chapter 4.1 can be considered as a bottom up approach regarding the validation, this chapter is focusing on a top down approach. As all data coming from the questionnaires are raw data, this chapter is focusing on the consistency and reliability of the chosen method in order to validate the results using that top down approach.

4.2.1 Residential buildings

Based on the explanations within chapter 2, the work of [BGW06] represents an appropriate way to validate with. Furthermore, the results of chapter 3.4, especially Figure 30, highlights that the electrical load profile is not a matter of the building age or its size. Therefore, the upcoming results are related to BC8-3. In order to validate the results all electrical load profiles created within this validation process assuming a unified consumption of 1000 kWh/yr. Figure 64 compares the result regarding the electrical load profile considering a week day within the winter period. The profile for the calculated mean value including the standard deviation for all milieus is showing an accurate match compared to [BGW06]. Due to the rough time step within the questionnaires (see chapter 3.4), the profile is not as smooth as the data of [BGW06], which are subject of a 15 minutes time step.

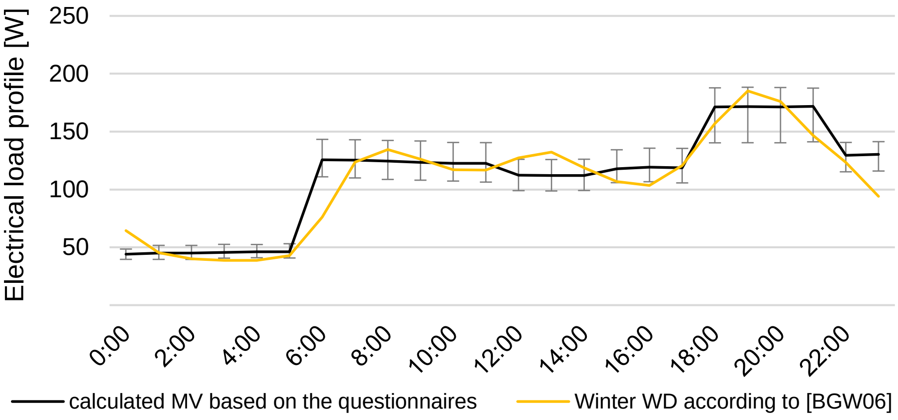

Figure 64: Comparison of the calculated electrical load profile for residential buildings including the maximum bandwidth with data from [BGW06], considering a winter week day (WD). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Nevertheless, the results regarding the calculated load profile address the same specific characteristics, such as morning and evening peak, as the data of [BGW06]. In contrast to Figure 64, Figure 65 addresses the same results but considering a weekend day within the winter period.

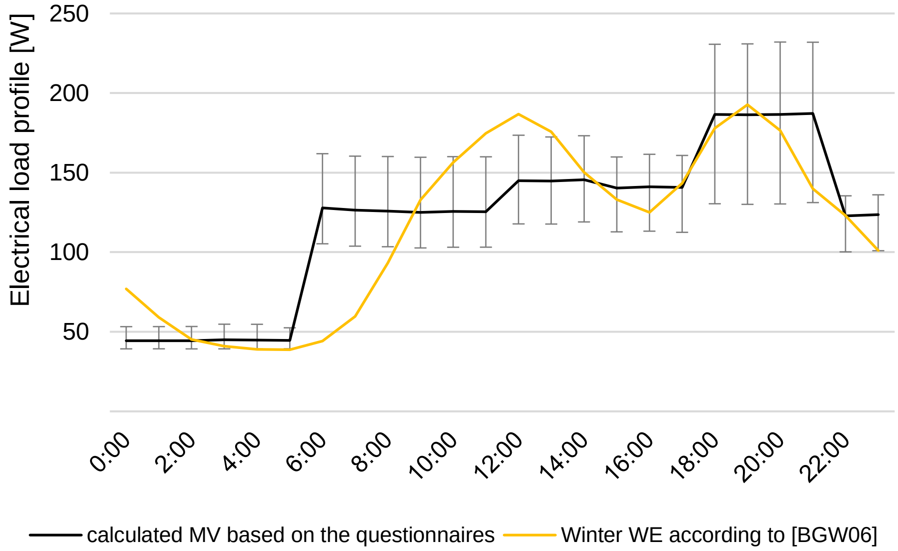

Figure 65: Comparison of the calculated electrical load profile for residential buildings including the maximum bandwidth with data from [BGW06], considering a winter weekend day (WE). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Unlike the results for a week day, the standard deviation shows a higher bandwidth and the accordance with data of [BGW06] is not as precise. This is due to the fact, that the questionnaires are using an even rougher time step and thus, raw data regarding the milieu based attendances within the weekend are insufficient. At least the peak loads can be characterized sufficiently within this method. In order to increase the accuracy within the weekend, a series of certain assumptions have to be made however, that will be part for a future work.

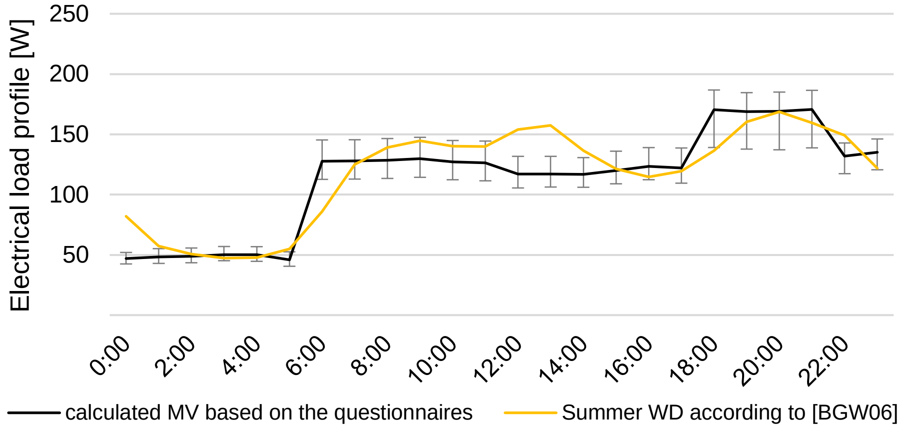

Figure 66: Comparison of the calculated electrical load profile for residential buildings including the maximum bandwidth with data from [BGW06], considering a summer week day (WE). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Figure 66 and Figure 67 follow the same procedure but considering the summer period. Even the results and their interpretation of certain characterizations are similar to the results related to the winter period.

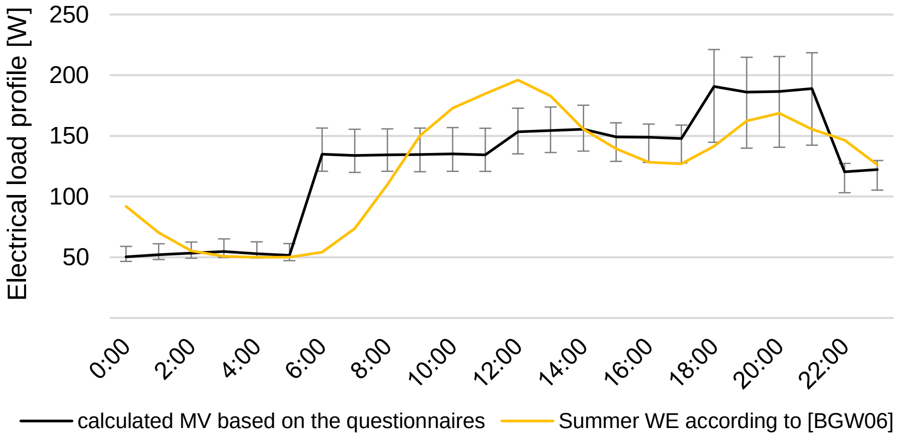

Figure 67: Comparison of the calculated electrical load profile for residential buildings including the maximum bandwidth with data from [BGW06], considering a summer weekend day (WE). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

A last overview regarding the comparison of all results with data of [BGW06] is given in Figure 68. Due to all lines representing a week day are continuous and all lines representing a weekend day are dashed, the differences regarding the accuracy are highlighted clearly.

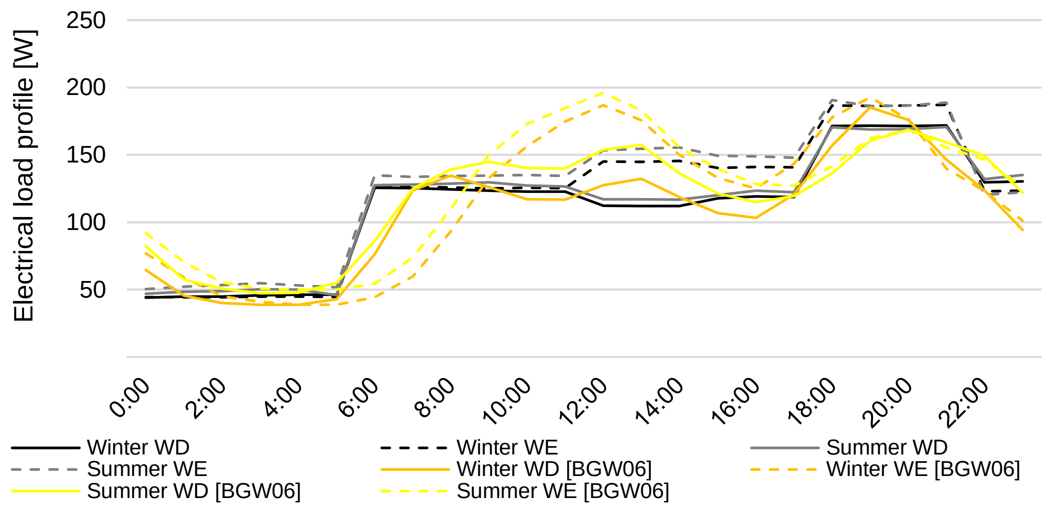

Figure 68: Summary and overview of all calculated electrical load profiles for residential buildings compared with data from [BGW06] for each period and day. Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Additionally, the results have been compared with data from [GHA11] and [HAU13], see chapter 2. While [GHA11] is focusing on daily load profiles in order to increase certain demand side management potentials, [HAU13] analyzes different behavior considering a social differentiation approach.

The results of [GHA11] emphasizes the importance of tight time steps. The comparison, regarding the peak loads considering a daily load profile for residential buildings are subject of a time step of 1 second and 15 minutes, shows a significant difference of about 5 times higher. That effect can also be observed in the conducted study of [JOR01] regarding the domestic hot water draw off profile. Furthermore, [GHA11] distinguishes between week days and weekends, as well as summer and winter. A qualitative comparison of the results with data of [GHA11] shows an incredible tight accuracy however, the peak loads within [GHA11] are more representative due to the tight time step. As URBEM uses a 1-hour time step for all work packages, higher time steps within that method are generally possible, but not in terms of interoperability within the URBEM simulation environment. Due to URBEM is aggregating all load profiles at the level of building neighborhoods, the importance of lower peak loads decreases anyway. Furthermore, the simulation efforts are more moderate, especially towards a comprehensive future co-simulation.

The work of [HAU13] focuses not only on all electrical appliances on a very detailed level, but also on social differentiation. This makes that work highly comparable. One key finding of [HAU13] addresses the issues regarding the qualitative and quantitative differences. While the household grouped by number of persons showed very little differences regarding the shape of their load-curve and were only differing in height, the lifestyle groups showed more substantial differences regarding the shape of their load-curve [HAU13]. The same phenomenon can be observed within this thesis. On the one hand, Figure 30 is underlining that there is almost no difference regarding the quantitative load profile by considering different building ages as well as building sizes. On the other hand, Figure 33 and Figure 34 show the qualitative differences by considering different milieus.

4.2.2 Office buildings

Likewise the procedure considering residential buildings in chapter 4.2.1 as well as the conclusions of Figure 30, the upcoming results are related to BC8-3 only. Due to this thesis is mainly focusing on residential buildings, but knowing the importance of office buildings, characteristic data from [HDZ14b] has been used to generate electrical load profiles. In the course of the validation process, the results have been unified in terms of assuming a 1000 kWh/yr electrical consumption, in order to validate with data from [BGW06]. Unlike the load profile generated in the course of the questionnaires, the data of [HDZ14b] are as smooth as the validation data of [BGW06] due to the high resolution of the metered data. The first result addresses the electrical load profile for a week day within the winter period, given in Figure 69.

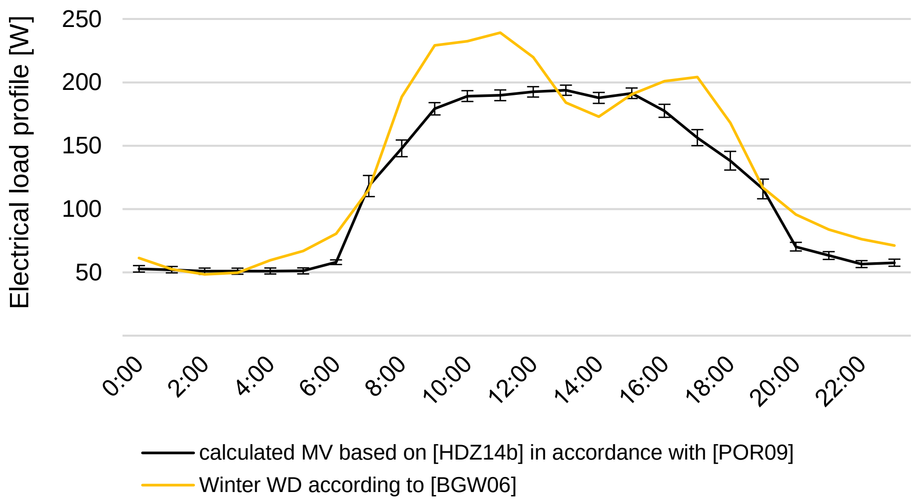

Figure 69: Comparison of the calculated electrical load profile for office buildings including the maximum bandwidth with data from [BGW06], considering a winter week day (WD). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

It is conspicuous, that the typically bend due to lunch breaks according to [BGW06] is not apparent, even though the profile has been established based on metered data with respect to the results of [PRO09]. This is mainly due to the fact, that electronic appliances do obviously not shut down within the lunch breaks as they are supposed to do. [HAR04], [HER06] and [MEN14] indicate similar results in terms of no typically lunch break bend. The qualitative load profiles of [HAR04] (based on a 15 minute interval of 17 office buildings) and [PER06] (for 9 office buildings) have an almost perfect match with the results of Figure 69 and Figure 72. Therefore, an overview of the results for the qualitative electrical load profiles from [HAR04] as well as from [HER06] are given in Figure 70.

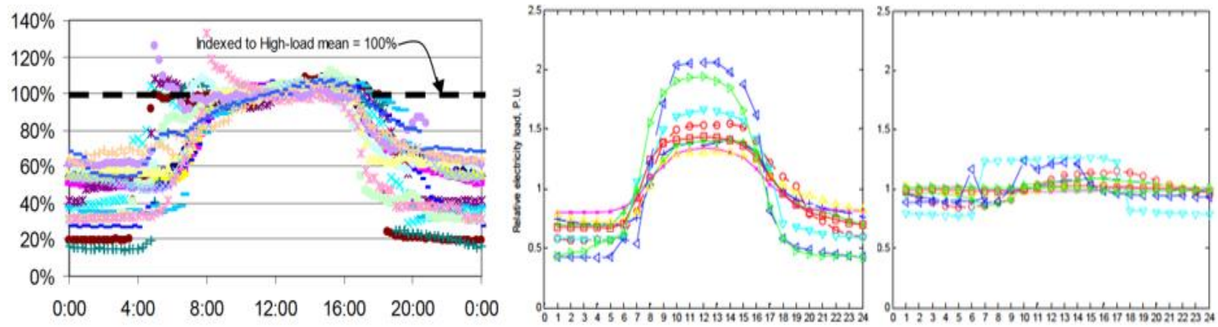

Figure 70: Qualitative electrical load profile according to metered data of 17 office buildings [HAR04] (on the left) and to 9 office buildings [HER06] (in the middle for WD and on the right for WE), in order to validate the results related to the electrical load profiles for office buildings within this thesis.

The same comparison can be made by considering a weekend day. Unlike the typical characterization for a week day, the electrical load profile for a weekend day remains constant. This due the fact, that mainly standby losses contribute to the electricity loads. The results for the electrical load profile considering a weekend day are given in Figure 71.

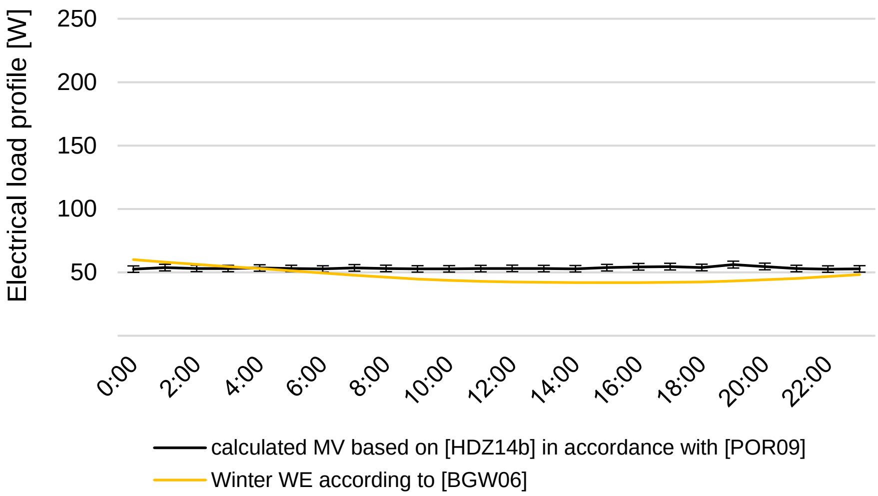

Figure 71: Comparison of the calculated electrical load profile for office buildings including the maximum bandwidth with data from [BGW06], considering a winter weekend day (WE). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Analogous to the results given in Figure 70 and Figure 71 with respect to the winter period, Figure 72 and Figure 73 address the results regarding the summer period.

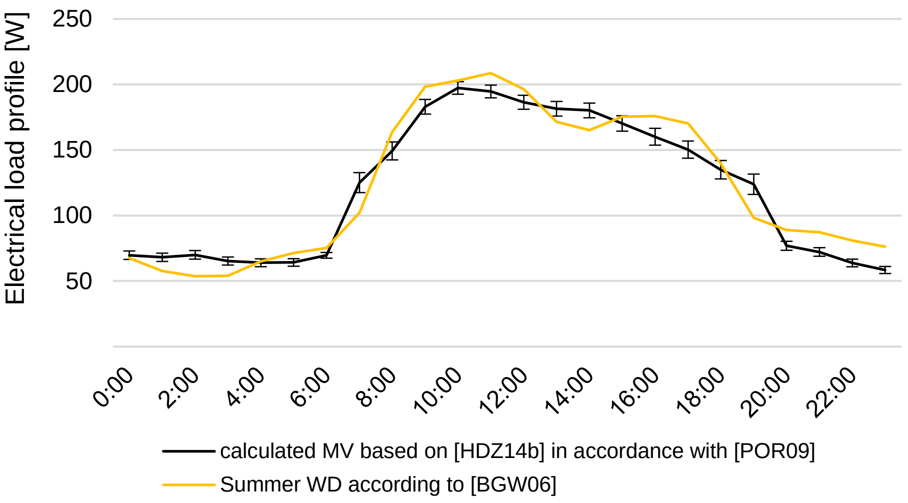

Figure 72: Comparison of the calculated electrical load profile for office buildings including the maximum bandwidth with data from [BGW06], considering a summer week day (WD). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

It is noticeable that the results related to the summer period are more corresponding than the results related to the winter period. Moreover, the electrical load profile is characterized by a decreasing load curve at the beginning of the afternoon. The reason for that characterizing decrease might be either a lower occupation or less efforts for lighting or both.

Figure 73 underlines the characteristics regarding the electrical load profiles considering a weekend day. Almost every weekend day shows slight differences even only standby losses contribute to the electrical load profile.

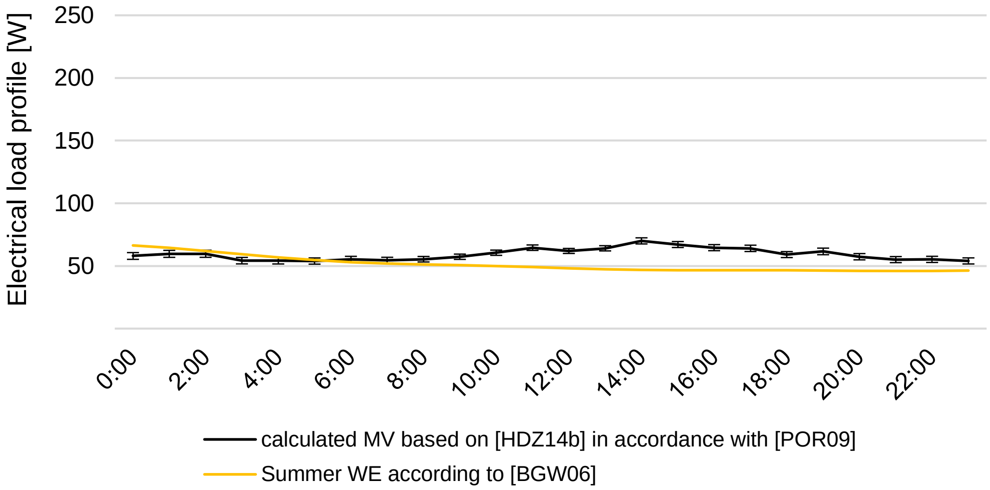

Figure 73: Comparison of the calculated electrical load profile for office buildings including the maximum bandwidth with data from [BGW06], considering a summer weekend day (WE). Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

Due to [BGW06] refers only to a mean value for an electrical load profile, differences regarding the real profile characterization for every single day can’t be addressed. Therefore, the data of [BGW06] are insufficient in order to validate dynamic time sensitive load profiles with respect to every single day. However, due to rare metered data available, [BGW06] represents a rare source to validate with.

In accordance with Figure 68 within chapter 4.2.1, Figure 74 concludes all results related to office buildings.

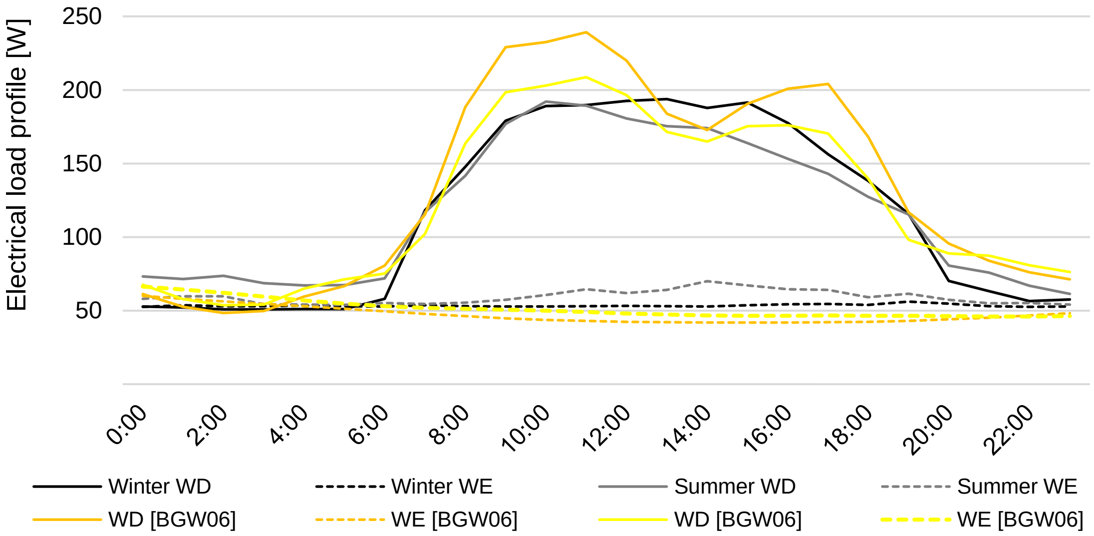

Figure 74: Summary and overview of all calculated electrical load profiles for office buildings compared with data from [BGW06] for each period and day. Due to [BGW06] created those data considering a cumulative electrical consumption of 1000 kWh/yr, the calculated load profile assumes the same unified electrical consumption in order to compare with.

4.2.3 Conclusion regarding the validation of electrical load profiles

The results underline the importance of knowing the qualitative and quantitative load profile characteristics. Furthermore, the results also highlight the differences considering metered data and data from appropriate literature. Due to electrical load profiles are significantly related the buildings occupation, there won't be the one and only electrical load profile to validate with. This fact emphasizes the importance of the method on how to create time sensitive electrical load profiles even more. The chosen method of using raw data in the course of a questionnaires is definitely appropriate however, some important issues can be encountered towards future research and more accurate data:

- The tighter the time step in terms of occupancy attendances within the questionnaires, the more accurate the results. Especially the time steps regarding a weekend day according to Table 15 are insufficient, see Figure 65 and Figure 67.
- Considering only residential buildings, all validation data are very useful and appropriate to compare with. Furthermore, the results correlate satisfactorily with the validation data.
- Considering office buildings, metered data are even more important. Validation data, such as [BGW06], show a bend within the lunch break. However, that characteristic bend

could have not been observed using metered data from [HDZ14b], [HAR04] and [HER06].

- Due to all electrical load profiles are varying every single day, the approach of assuming a unified consumption in order to compare the load profile characteristics has a lot of advantages. Not only to emphasize the differences regarding the qualitative profile, but also to increase the quantity of useful validation data.
- The last finding applies to all created electrical load profiles: only the use of a dynamic building simulation tool enables the advantages of using raw data in the course of a questionnaires. Otherwise, the results are either balanced at different boundaries (e.g. E_b or E_t of [IEA13]), or the input parameters are not related to dynamic restrictions (e.g. real attendance, summer/winter, holiday, as well as their specific simultaneity ratios).

5 Results

The last sub chapter focuses on the capabilities of this method in order to outline the differences of final predicted load profiles related to the objectives given in chapter 1.3 and 1.4. However, the following results can be considered as the sum of individual and interdisciplinary sub results related to:

- a detailed understanding regarding building physics parameters as well as the method of using density functions – see chapter 3.2
- the effects of different HVAC strategies onto specific load profile characteristics – see chapter 3.3,
- taking advantage of using a milieu oriented approach in order to distinguish energy load profiles with respect to social differentiation – see chapter 3.4,
- the development of an interdisciplinary building simulation setup in order to create density function with respect to the UBREM objectives – see chapter 3.6
- and the significant findings in the course of the validation procedure – see chapter 4.

Based on the validation results the developed simulation model shows a great accordance to the validation data. Nevertheless, some single criteria's such as the bandwidth within weekend days are not satisfactory. Therefore, the simulation model has been used to create all scalable energy load profiles in accordance with the load profile matrix given in chapter 3.5. While chapter 4 focuses on the validation of qualitative and quantitative load profiles, this chapter highlights the strengths of this method in order to outline the differences of certain energy load profiles and their crucial characteristics due to the impact of different scenarios considering building physics, HVAC as well as the occupation. All upcoming results are based on the method of using scalable energy load profiles instead of a detailed building simulation tool. In order to make various of building models comparable almost all results assume a unified energy consumption.

5.1 Impact due to different construction and mechanical engineering technologies onto predicted energy load profiles

The results of this chapter are focusing on the load profile differences taking into account the impact due to different building physics parameters and mechanical engineering technologies. Furthermore, all results are based on the method of using scalable load profiles instead of a detailed building simulation. All building physics parameters are related to chapter 3.2 and the differences regarding the mechanical engineering system (HVAC design) are related to chapter 3.3. An overview of all considered variants is given in the load profile matrix within chapter 3.5.

The first result addresses the differences regarding the heating load profile with respect to different buildings according to the building cluster. Knowing that an annual approach is inappropriate in order to derive any new findings, Figure 75 underlines the different load profile characteristics of BC1-3, BC4-3 and BC6-3.

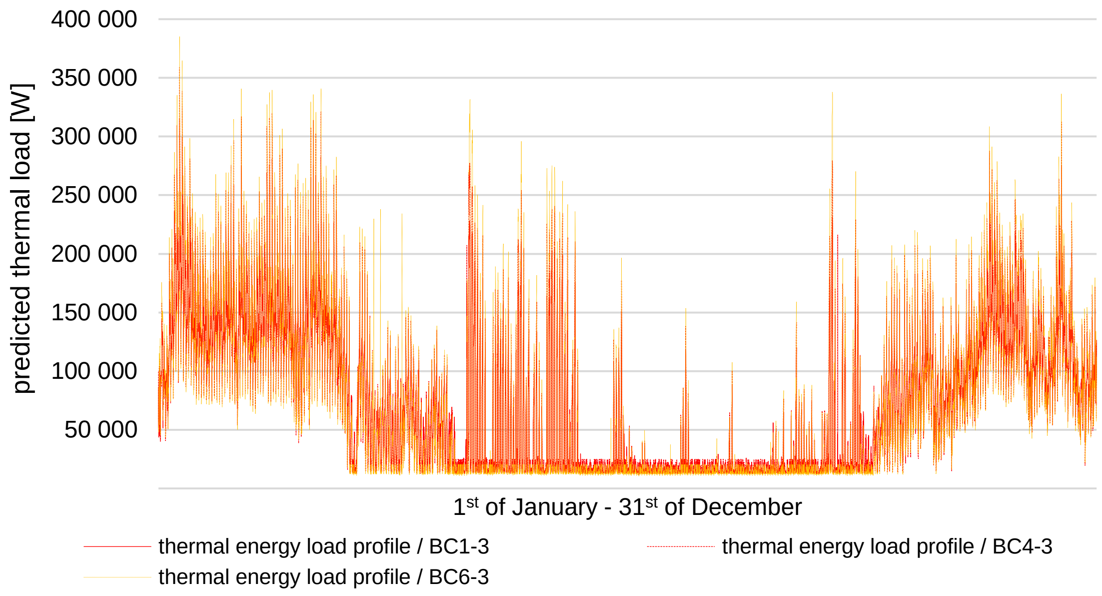

Figure 75: Annual heating load profile considering only BC1, BC4 and BC6, in order to underline the differences regarding their heat profile characteristics, assuming a unified annual energy consumption.

Even by using the approach of assuming a unified consumption, the qualitative differences within BC1, BC4 and BC6 are enormous. In order to gather a deeper understanding regarding the differences of thermal load profiles related to different buildings, both Figure 76 and Figure 77 are showing a daily plot of those issues. Figure 76 addresses the capability of this method in order to outline the differences regarding the thermal load profile characteristics related to the building age according to the building cluster.

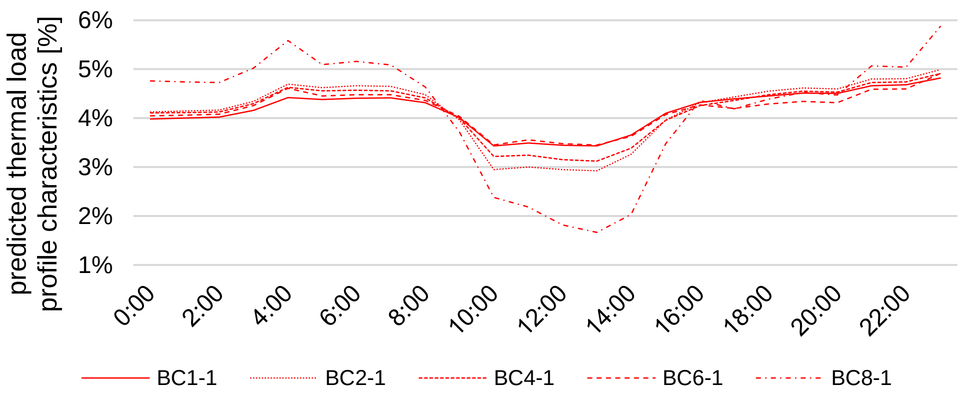

Figure 76: Comparison of the thermal load profile characteristics with regards to the building age (according to the building cluster), assuming a unified annual energy consumption. This plot represents a residential building considering a winter week day. Furthermore, this plot addresses only the impact for the heating load profile, not for the DHW.

According to Table 3 the buildings mass is varying significantly with regard to its age. The higher the building mass, the smoother the characteristics of its thermal load profile. As BC8-1 represents a new building, the building mass is relatively low and thus, makes the profile more related on the occupation. Moreover, the impact due to solar gains and better insulation can be observed. While BC1-1 represents the oldest building cluster with the highest building mass, the profile is much smoother trough out the day and thus, makes the thermal load profile more unrelated to the occupation. Analogues to the results for a winter week day in Figure 76, Figure 77 represents a winter weekend day.

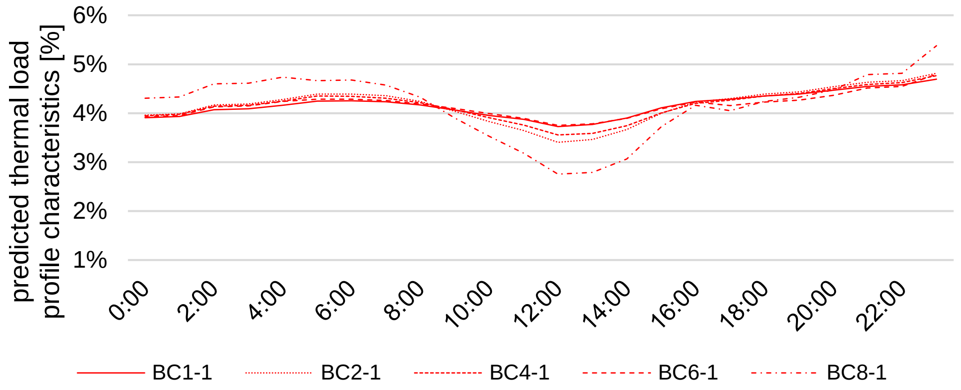

Figure 77: Comparison of the thermal load profile characteristics with regards to the building age (according to the building cluster), assuming a unified annual energy consumption. This plot represents a residential building considering a winter weekend day. Furthermore, this plot addresses only the impact for the heating load profile, not for the DHW.

Due to the higher attendances during the weekend, peak loads mainly caused by the working day routine, almost disappear. Therefore, the characteristics within the weekend day are smoother, even the predicted thermal energy consumption is higher.

The next finding focuses on the differences related to the occupation with regards to residential and office buildings. The purpose of Figure 78 and Figure 79 is to highlight the differences for identical load profiles, but for different buildings regarding their age.

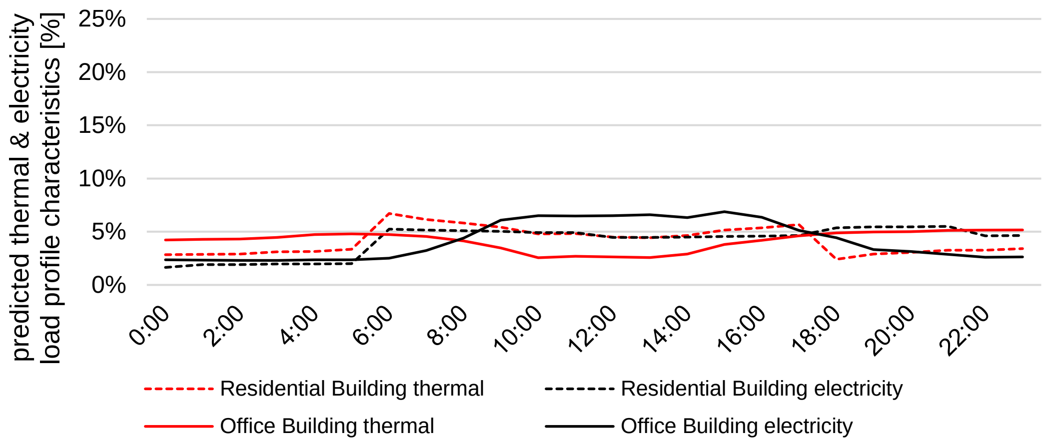

Figure 78: Comparison of the thermal and electrical load profile characteristics for a residential and office building, assuming a unified annual energy consumption. This plot is based on BC1-1 and a winter week day.

Figure 78 represents building BC1, which is the oldest within the building cluster. On the other hand, Figure 79 represents the newest building. Considering the qualitative heating profile, enormous differences can be observed.

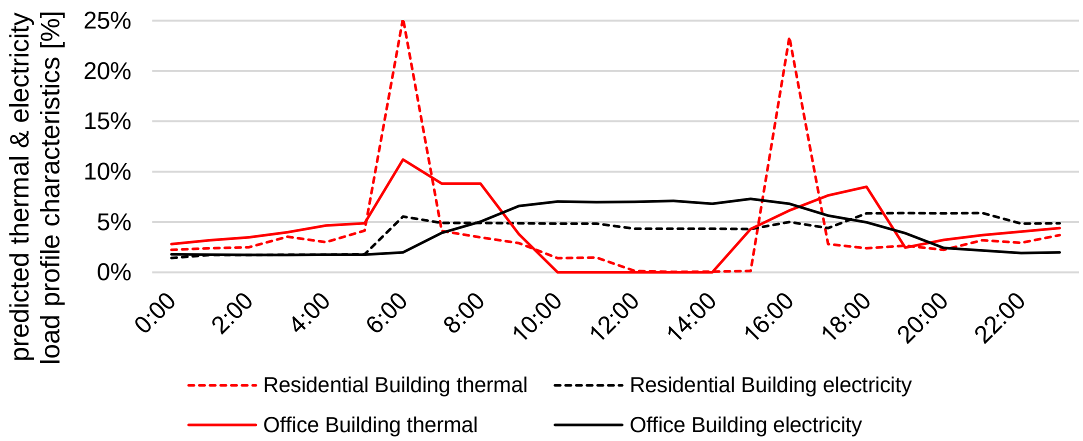

Figure 79: Comparison of the thermal and electrical load profile characteristics for a residential and office building, assuming a unified annual energy consumption. This plot is based on BC8-1 and a winter week day.

Both, Figure 78 and Figure 79 have intentionally the same axis scale in order to highlight the differences. While BC1 has almost no significant heating peak loads the peak loads for BC8 can be easily observed. This is due the fact that the predicted domestic hot water consumption of residential buildings, taking into account only new residential buildings, contributes to the heating load profile in terms of peak loads by far the most. The lower the general heating demand, the higher the contribution of the domestic hot water in terms of heating loads. This makes every energy load profile related to the domestic hot water use the most important driver towards a detailed understanding of time sensitive load profiles. However, as given in chapter 6 energy storages have not been considered so far. Taking into account the DHW profile, the consideration of energy storages will reduce the peak loads. Unlike the results for the thermal load profile characteristics, the electrical load profile characteristics remains constant and thus, makes the electrical load profile characteristics more or less unrelated to the entire building cluster. This can be also observed within Figure 80.

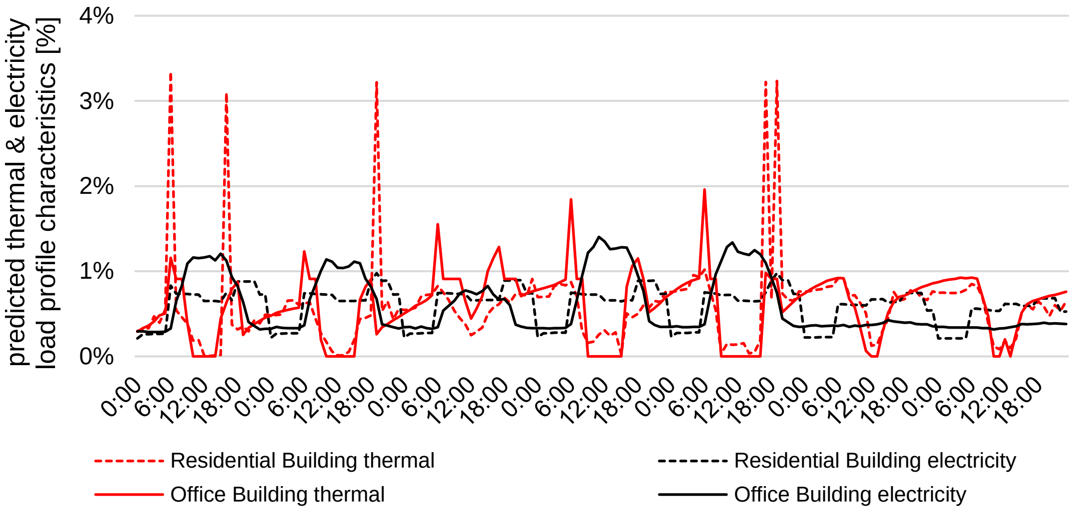

Figure 80: Comparison of the thermal and electrical load profile characteristics for a residential and office building, assuming a unified annual energy consumption. This plot is based on BC8-1 and a winter week.

Figure 80 considers an entire winter week considering the thermal and electrical load profile for a residential and office building. Based on the results for the electrical load profile, the differences regarding working day and weekend, morning and afternoon, day and night, residential and office building can be easily observed. While the electricity load profile remains logically, the thermal load profile respectively their peak loads are varying a lot due to the significant contribution of the predicted domestic hot water consumption. Within a single day, the peak loads related to the domestic hot water can be 2-5 times higher compared to the peak loads related to the heating system. Even those sophisticated details can be addressed using the method of scalable load profiles instead of a detailed simulation tool.

The last figure within this sub chapter, addresses the impact onto the load profiles by different HVAC designs. Therefore, Figure 81 shows the identical load profile characteristics for the office building given in Figure 80, taking into account a district heating system and a heat pump system.

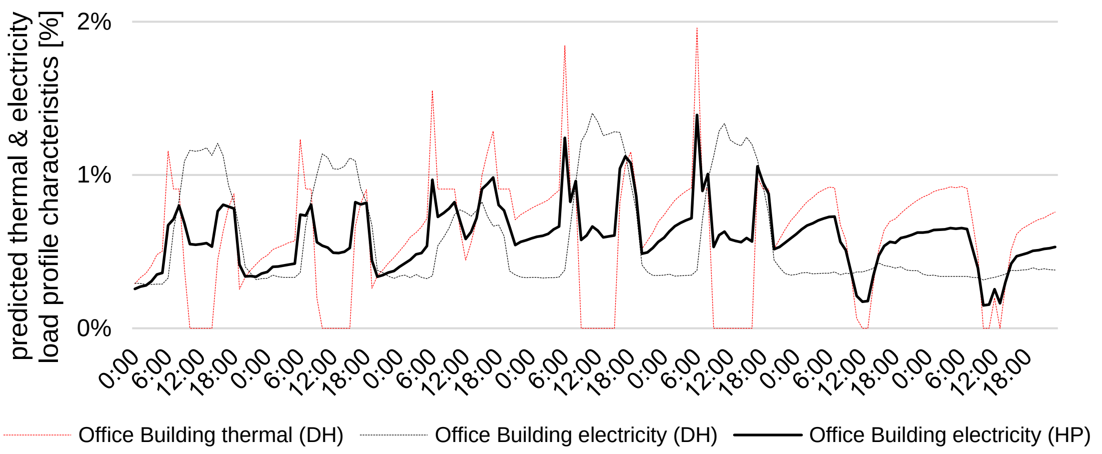

Figure 81: Comparison of the thermal and electrical load profile characteristics for an office building taking into account district heating and a heat pump. This plot is based on BC8-1 and a winter week.

Due to heat pumps are electric driven appliances the thermal and electrical load profile merges to only one electrical load profile. Thus, makes the characteristics of the profile changing significantly. Due to this merging effect, typical occasions, such as day and night, working day and weekend, etc. with regard to the findings in Figure 80, are not as easy to observe.

5.2 Impact due to social differentiation onto predicted energy load profiles

While chapter 5.1 is focusing on the load profile differences taking into account the impact due to different building physics parameters and mechanical engineering technologies, this chapter underlines the importance of a milieu based approach. Like the previous results, all results within this chapter are based on the method of using scalable load profiles. Summarizing the findings within chapter 3.4, the most crucial input is given in Figure 82.

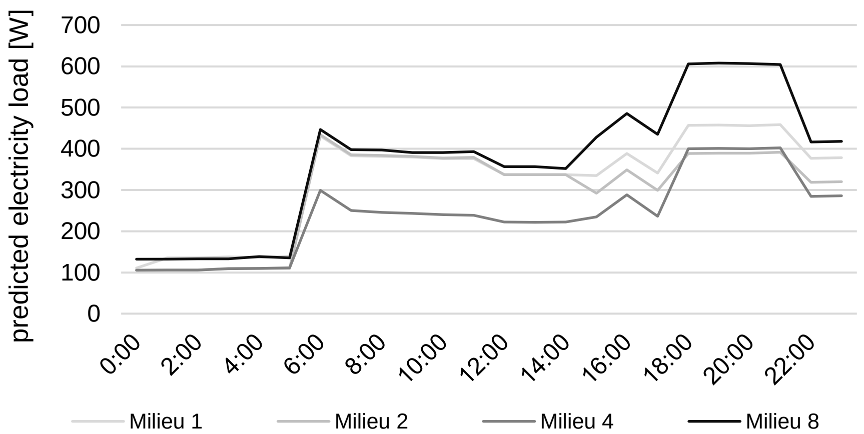

Figure 82: Comparison regarding the electrical load profile for milieu 1, 2, 4 and 8.

According to Figure 33 and Figure 34 within chapter 3.4, the upper and lower bandwidth for the electrical load profile is mainly caused by milieu 1,2,4 and 8 and thus, those milieus can be considered as maximum and minimum bandwidth for all further results.

Unlike the milieu based results for the electrical load profile, the thermal load profile characteristics given in Figure 83 show no significant difference regarding the occupation.

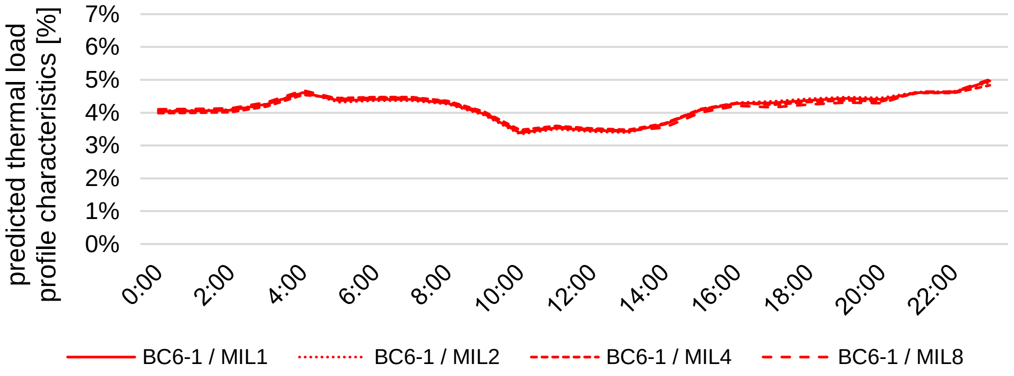

Figure 83: Thermal load profile characteristics for milieu 1,2,4 and 8 considering BC6-1, assuming a unified annual energy consumption, taking into account only to the heating consumption.

However, according to the significance of the building mass, solar and internal gains (see Figure 76 and Figure 77), a variation in terms of thermal load profile characteristics can be seen at buildings within BC8, taking into account the different occupation behavior of milieu 1,2,4 and 8.

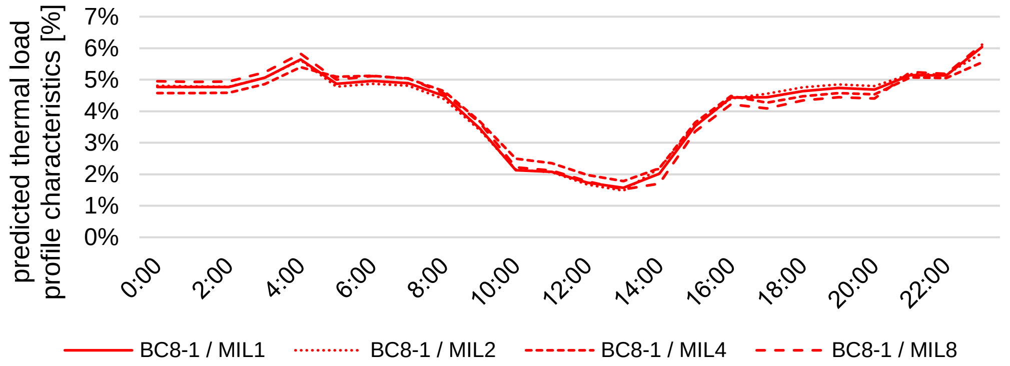

Figure 84: Thermal load profile characteristics for milieu 1,2,4 and 8 considering BC8-1, assuming a unified annual energy consumption, taking into account only to the heating consumption.

Due to the lower building mass, the thermal load profile relates more on the occupation and thus, the influence of the milieu based approach becomes more visible. Analogues to results for BC8-1, the results for BC8-3 are given in Figure 85.

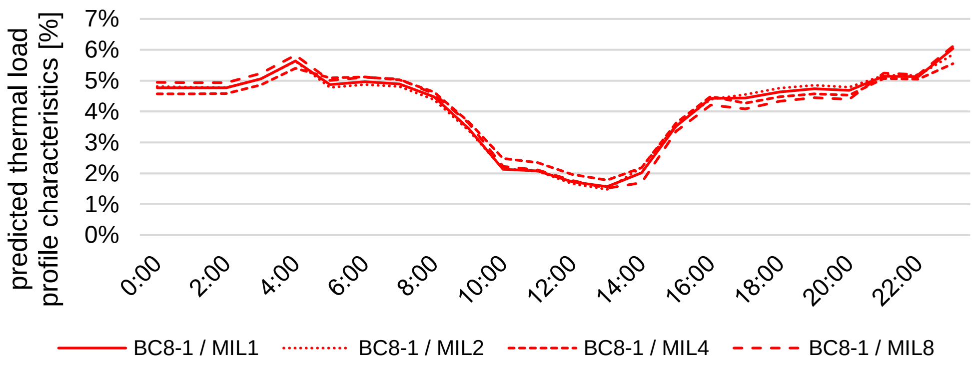

Figure 85: Thermal load profile characteristics for milieu 1,2,4 and 8 considering BC8-3, assuming a unified annual energy consumption, taking into account only to the heating consumption.

Unlike the comparison of BC6-1 and BC8-1, the comparison of BC8-1 (Figure 84) and BC8-3 (Figure 85) shows an almost identical thermal load profile characteristic for milieu 1,2,4 and 8. Thus, the specific thermal load profile characteristics are not a matter of the building size, but a matter of its age. Besides the understanding regarding the heating and electrical load profile, the key findings regarding the thermal load profile for the domestic hot water are even more important. Figure 86 highlights the huge variance due to the different occupation for the same building.

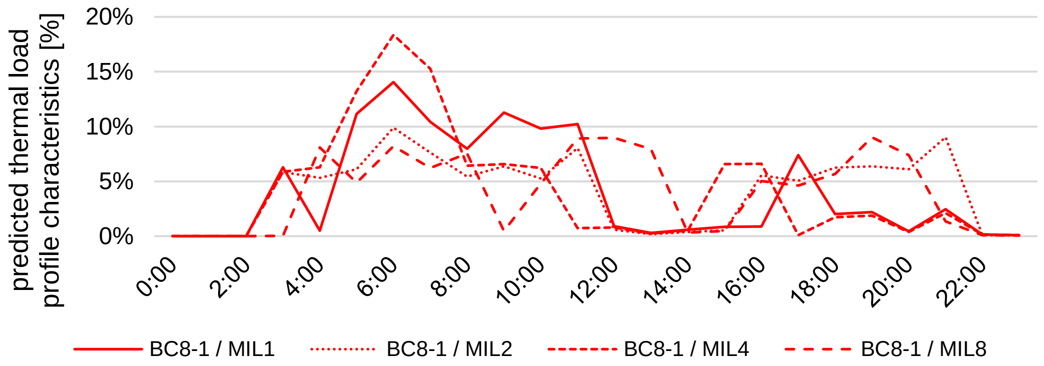

Figure 86: Thermal load profile characteristics for milieu 1,2,4 and 8 considering BC8-1, assuming a unified annual energy consumption taking into account only to the DHW without considering a circulation pipe.

According to chapter 3.4, the predicted hot water consumption for each milieus differs not only quantitatively, but also qualitatively. Furthermore, the profiles for each milieus and each day is varying. Thus, the impact onto the thermal load profile by the occupation is even more significant. As single family buildings are not equipped with a circulation pipe, multifamily buildings have to be equipped with a circulation pipe due to hygiene reasons. Thus, the energy consumption for the domestic hot water is higher due to more transportation losses (see also Table 31). This fact impacts the thermal load profile characteristics for the domestic hot water consumption significantly.

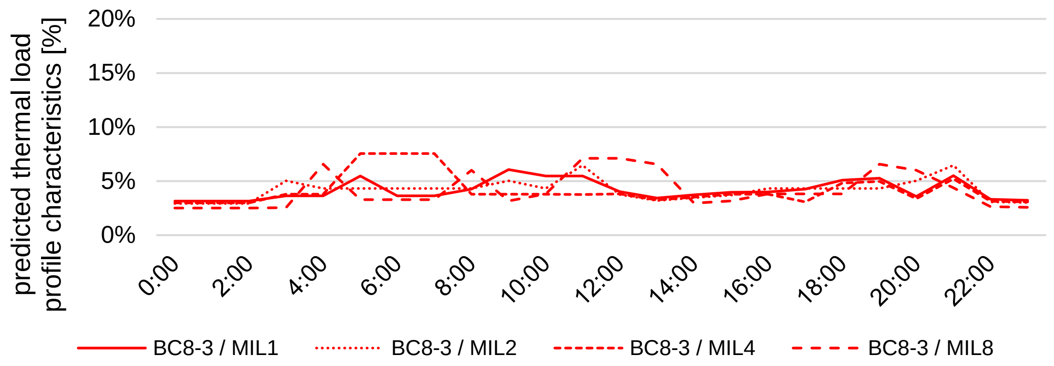

Figure 87: Thermal load profile characteristics for milieu 1,2,4 and 8 considering BC8-3, assuming a unified annual energy consumption related only to the DHW considering also a circulation pipe.

As Figure 86 and Figure 87 refers to the same week, the absolute draw off profile for the domestic hot water for each milieu is identical however, the thermal load profile characteristics for both cases differs significantly.

5.3 Impact due to the URBEM scenarios onto scalable load profiles

Primarily, the URBEM simulation environment serves as decision support tool and thus, its performance regarding time efficiency, accuracy and expandability can be considered as top priority with respect to the URBEM scenarios. According to [SCH16b], each work package within the URBEM can be considered as an individual domain expert delivering individual and specific outputs within that holistic simulation environment. Secondly, each work package is subject of certain URBEM scenarios. Therefore, certain scenario parameters have to be used in order to deliver results for a holistic decision making process. The most important scenarios regarding the work package addressed within this thesis are given in Table 1. As the scenarios parameters serve as input, those parameters can be used to initialize all scalable energy load profiles for both, thermal and electrical energy. According to chapter 3.6, 3528 scalable load profiles have been created in the course of this thesis. 2520 load profiles are related to residential buildings and 1008 are related to office buildings. In terms of building age and its size, 21 different buildings according to the building cluster given in chapter 3.2.2 can be used for different scenarios. There are 9 available technologies regarding the heating systems and 6 available technologies regarding the DHW system. Furthermore, the method of social differentiation delivers 10 different load profile characteristics considering the milieu based approach of [HAU16a] and [HAU16b] as well as 3 different occupation scenarios for office buildings.

The scenario sequence in order to initialize all scalable energy load profiles is given in Figure 88. The final methodology to initialize the energy load profile is given in chapter 3.6.4.

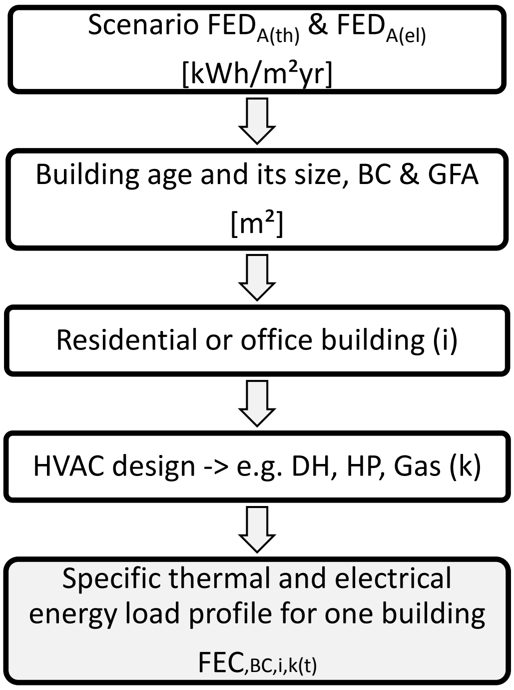

Figure 88: Scenario sequence in order to create a scenario based scalable energy load profile according to chapter 3.6.4.

Due to the clusters of sub matrixes regarding the initializing process for all URBEM scenarios, a logical method in order to simplify that process has been established within chapter 3.5. This fact does not only simplify the data management within the URBEM simulation environment, but also ensures a consistent workflow for all scenarios within the UBREM.

5.4 Conclusions regarding the capabilities of scalable load profiles

The results within chapter 5 show clearly that the method within this thesis is capable not only to address, but also to highlight specific and sophisticated issues taking into account:

- different building physics parameters and their impact on energy load profiles on a very detailed level (see Figure 75 to Figure 77),
- how thermal and electrical load profiles are related to the occupation, considering residential and office buildings (see Figure 78 to Figure 80),
- the impact of different HVAC designs onto the energy load profile considering the thermal and electrical load profile characteristics (see Figure 81),
- the importance of the milieu based bandwidth related to the electrical load profile (see Figure 82),
- the impact of different milieus onto the thermal load profile characteristics (see Figure 83 to Figure 85),
- the effects of different domestic hot water strategies onto the thermal load profile characteristics (see Figure 86 and Figure 87),

- as well as the sequence in order to initialize the most appropriate scalable load profile according to the URBEM scenarios (see Figure 88).

Furthermore, the method of using scalable energy load profile with respect to all objectives within this thesis delivers 2 key findings:

- Firstly, due to the comprehensive simulation efforts considering all possible variants (e.g. occupation, buildings age, HVAC design, etc.), significant differences and specific relations regarding the energy load profile characteristics could be observed on a very detailed level. Furthermore, the results emphasize to focus on an hourly load profile to address all issues towards a detailed understanding regarding the technical link of buildings and energy grids.
- Secondly, due to all scalable energy load profiles are derived from comprehensive and validated simulation results, sophisticated load profile characteristics can now be addressed without running time intense and detailed building simulation engines for each individual building within a district or even within an entire city.

6 Conclusions and Outlook

The method of using scalable energy load profiles has shown a various of advantages compared with individual and detailed building simulation models. Furthermore, this method perfectly meets the URBEM objectives in order to run a comprehensive urban simulation environment. Due to its great accuracy and time efficiency with respect to the URBEM objectives, the UBREM simulation environment can be used as an accurate, powerful, interactive as well as reliable decision support tool towards a sustainable, secure supply, affordable and liveable city.

Since URBEM is a comprehensive and interdisciplinary research cooperation, the method of using scalable energy load profiles bundles not only the interdisciplinary disciplines of buildings physics, mechanical engineering and sociological differentiation, but also highlights the holistic and comprehensive interaction within all URBEM disciplines.

The results of all scalable load profiles have shown a great capability regarding the impact of different building physics parameters, HVAC designs and occupation scenarios onto time sensitive energy load profiles without using individual and detailed building simulation models. Thus, this method enables the use of time and location sensitive energy load profiles for an entire city within an hour without neglecting valuable capabilities of detailed building simulation engines.

Table 34: Comparison regarding the time efficiency for individual simulations and the method of using scalable energy load profiles with respect to the UBREM objectives.

	Individually	Pre-simulation	Scalable load profiles
Number of simulation runs	180 000[1]	273[2]	-
Number of load profiles	180 000[1]	273[2]	3 528
Simulation time for 1 building	25 min[3]	25min	< 1 sec
Simulation time for 180 000 buildings	30 000 hours 3.5 years	113.75 hours	1 hour
Deviation regarding the accuracy	baseline	baseline	+0.8% / - 1.19%[4]

[1] … according to the building stock of Vienna; [2] … derived from the given buildings cluster and occupation scenarios; [3] … mean value for one simulation run; [4] … according to the results of [ZIE16c]

Furthermore, all scalable energy load profiles get initialized by certain scenario parameters. Thus, only the input of certain scenarios is necessary in order to create time sensitive energy load profiles for a buildings block or even for the entire city. This fact makes this method highly valuable for scenario play, holistic technology assessments as well as their impact onto the local energy supply grid. Additionally, a new method regarding the implementation of a milieu oriented approach has been established. The results have shown significant differences regarding the electrical load profile characteristics considering 10 different milieus. However, the method has also shown its limits regarding uncertainties due to the lack of data or implausible questionnaires. Therefore, a consistent over writing procedure has been established in order to safe data appropriately instead of deleting them. Nevertheless, the results address the impact of different occupation scenarios significantly and will strengthen the awareness towards an enhanced understanding regarding the real occupancy.

In order to balance at the level of the predicted final energy consumption, a comprehensive HVAC design model has been established. Its modular and expendable structure enables not only a time sensitive consideration of specific HVAC design characteristics, but also a comprehensive scenario play concerning the future energy supply and the related urban challenges due to the energy consumption of buildings.

Furthermore, the simulation setup enables technical upgrades due to its modular structure easily. Thus, results of related research projects (e.g. buildings physics, mechanical engineering and occupation) can be added without recoding the entire simulation setup. Additionally, an algorithm has been established in order to make the pre-simulation for all scalable energy load profiles completely automated. Since URBEM focuses on Vienna and some validation data do the same, most of the results are related to Vienna. However, the structure, its specific architecture as well as the pre-simulation sequence of this method are suitable in order to address other building neighborhoods or cities. Therefore, only specific buildings physics characteristics have to be adjusted as well as new questionnaires are needed in order to bring in the milieu oriented approach.

URBEM can be considered as a comprehensive urban decision support prototype. However, the recent results and methods highlight also the path regarding necessary future work. An essential step would be a comprehensive validation procedure with high resolution data regarding the energy load profiles for building blocks, but simultaneously knowing the share of its real occupation (e.g. 10% milieu 2, 23% milieu 8, etc.).

Due to the results for individual buildings have a great accuracy, the setup of the building cluster regarding their ages and sizes can be considered as sufficiently. However, an additional consideration concerning new buildings (e.g. BC9; >2010) would be a major step towards a more detailed consideration of new building technologies. The capability of those building models will address the impact due to thermal activated building systems, decentralized energy generation systems as well as significant differences regarding the controlling strategies. However, the more sophisticated the building technologies the higher the requirements regarding the simulation models. Thus, in order to address those impacts accurately, the building models for the pre-simulation have to be setup with more thermal zones (e.g. controlling strategies) and with more precise data regarding the walls layer (thermal activated building systems). Therefore, a future step would be to find a proper way to bridge the gap concerning the more detailed and the higher the requirements regarding the capabilities of energy load profiles the more data are needed.

The results within this thesis serve mainly the energy grid operator in order to be prepared regarding peak loads or low loads with respect to a certain location and time. Thus, all scalable energy load profiles have been divided within Vienna in order to generate location based aggregated energy load profiles for the thermal and electrical grid. Therefore, the results serve as input for those work packages within the URBEM. However, this can be considered as an uni-directional data flow. In order to address future efforts regarding the implementation of demand side management measures, a suitable method to enable co-simulation between buildings and energy grids would be a major future step. Due to the lack of data for both buildings and energy grids, that method should focus only on the level of building neighborhoods in a first step.

The results regarding the milieu based energy load profiles have been satisfactory, even though some specific issues haven't been addressed sufficiently. In order to enhance the milieu based electrical load profiles regarding weekends, off-days or even for long term holidays, more detailed answers as well as a greater amount of participating people in the course of the questionnaires are necessary. However, the questionnaires are subject of time restrictions and thus, cannot fulfill the requirements of all work packages within the URBEM simultaneously. Therefore, based on the current questionnaires, an additional and dedicated questionnaires concerning buildings in general would be the basis in order to gain more information's towards more detailed and time sensitive energy load profile. Moreover, the combination of highly metered energy consumption data with a detailed knowledge regarding the real occupation would be highly valuable in order to enhance the capabilities of this method.

An additional strength of the URBEM simulation environment regarding the methods within this thesis is to validate using a top down approach using the results of the simulation models related to the thermal and electrical grid. As those results are also subject of a validation procedure using metered data coming from the grid operator, the results are highly valuable in order to compare with aggregated results regarding the buildings energy load profiles. Furthermore, all results are also dedicated to certain locations (e.g. a certain building neighborhood). A preliminary comparison has shown, that the qualitative load profiles performs more or less like the metered data coming from the grid operator. Even the predicted annual energy consumption performs sufficiently. However, due to the uncertainties whether a house is occupied or not, or has installed a cooling system or not, the quantitative load profiles in terms of peak loads show different results. Thus, the vacancy rates regarding buildings and the knowing of the real technical equipment related to the occupation becomes more important. For instance, whether a building is occupied or vacant, or is cooled or not, have been assumed in the course of the URBEM scenarios. However, this fact influences the overall results regarding the energy grids significantly and thus, makes this fact worth for future work.

Finally, the results for the URBEM simulation environment as well as for all sub models of each dissertation, in particular the methods within this thesis, have demonstrated a high level prototype towards a comprehensive decision support tool. A various of problems have been solved in the course of URBEM, but a various of future problems have been found. The results within this thesis highlight the importance of an enhanced understanding concerning buildings and their role within a city. Furthermore, the results enable to visualize and emphasize the impact due to different building types, occupation scenarios as well as HVAC designs on the overall systems.

7 Appendix

7.1 Figures

7.2 Tables

7.3 Bibliography

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7.4 Abbreviations

Abbreviation	Description
BC	Building Cluster in terms of naming
CC / KM	Cooling Ceiling
CH-P / KM-P	Chiller – Piston compressor
CH-S / KM-S	Chiller – Screw compressor
CH-T / KM-T	Chiller – Turbo compressor
COP	Coefficient of Performance
DF	Density Function
DH / FW	District Heating
DHW	Domestic Hot Water
EER	Energy Efficiency Ratio
FC	Fan Coil
FEC	Final Energy Consumption
FED	Final Energy Demand
FH / FBH	Floor Heating
GFA	Gross Floor Area
HP-A / WP-A	Heat Pump Ambient
HP-G / WP-G	Heat Pump Ground/Soil
HP-W / WP-W	Heat Pump Water
HVAC	Heating / Ventilation / Air Conditioning
ICT	Information and Communication Technologies
MIL	Milieu
MV	Mean Value
OB / NWG	Office Buildings
RH / Rad	Radiant Heating
RD / WG	Residential Buildings
SD	Standard Deviation
TABS / BTA	Thermal Activated Building Structure
TU Wien	Vienna University of Technology
URBEM	Urban Energy and Mobility System
WD	Week day
WE	Weekend day
WP	Work package
WStW	Wiener Stadtwerke Holding AG

7.5 Building cluster

Table 35: Geometrical data in accordance with Table 3 and Table 4 regarding the building cluster in the course of the pre-simulation procedure.

BC	1-1	1-2	1-3	2-1	2-2	2-3	4-1	4-2	4-3	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2	7-3	8-1	8-2	8-3
GFA [m²]	102	3520	6600	102	3080	8580	102	2925	7875	102	2925	5711	408	2039	5711	102	3060	5400	102	3060	5400
Stories [-]	2	4	5	2	4	5	2	3	7	2	3	7	2	5	7	2	6	6	2	6	6
lc [m]	1.23	4.06	4.77	1.23	3.94	4.96	1.21	3.21	4.42	1.23	3.21	3.12	1.79	2.72	3.12	1.11	3.36	4.1	1.11	3.36	4.1
Length [m]	10.92	40	60	10.92	35	78	10.92	65	75	10.92	65	87.36	21.84	43.68	87.36	10.92	34	40	10.92	34	40
Width [m]	4.67	22	22	4.67	22	22	4.67	15	15	4.67	15	9.34	9.34	9.34	9.34	4.67	15	22.5	4.67	15	22.5
Height [m]	10	19	23.5	10	19	23.5	9.4	13.6	30.4	10	13.6	25.5	8	18.5	25.5	7	19	19	7	19	19
Window/Wall ratio north [%]	20	25	15	30	15	25	25	40	20	22	10	30	27	35	20	39	32	30	0	61	31
Window/Wall ratio east [%]	20	15	25	30	25	15	25	10	30	22	40	20	27	20	35	21	61	42	39	32	42
Window/Wall ratio south [%]	20	25	15	30	15	25	25	40	20	22	10	30	27	35	20	71	32	35	22	71	52
Window/Wall ratio west [%]	20	15	25	30	25	15	25	10	30	22	40	20	27	20	35	0	71	51	71	32	35