DIPLOMARBEIT

Thermal analysis of a renovation project: Assessment of Achieved Improvement in Energy Performance

unter der Leitung von

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KURZFASSUNG

Es ist allgemein bekannt, dass Gebäude derzeit für einen Großteil des Energieverbrauchs und der Treibhausgasemissionen verantwortlich sind. Unter anderem deshalb wurden in den letzten Jahren die Bauvorschriften im Hinblick auf die Energieverbrauchsgrenzwerte von Gebäuden verschärft. Solche Vorschriften zielen in der Regel auf neue Gebäude ab. Angesichts der eher niedrigen Neubaurate muss aber auch der Gebäudebestand adressiert werden, um die Klimaziele zu erreichen und die Auswirkungen des Klimawandels abzumildern. Dabei gilt vor allem die Gebäudesanierung als eine Lösung zur Senkung des Energiebedarfs und der Treibhausgasemissionen bestehender Gebäude.

Aus technologischer Sicht wird die Gebäudesanierung als nicht übermäßig komplexe Tätigkeit angesehen: Üblicherweise wird entweder eine Dämmung von Bauteilen der Gebäudehülle durchgeführt, oder aber Bauteile, die die energetischen Anforderungen nicht zufriedenstellend erfüllen, werden ausgetauscht. Sowohl normative Berechnungen als auch dynamische Simulationen können verwendet werden, um die Auswirkungen von Sanierungsmaßnahmen auf verschiedene wichtige Leistungsaspekte von Gebäuden zu bewerten. Untersuchungen der Vergangenheit haben jedoch gezeigt, dass in vielen Fällen, Lücken zwischen der erwarteten (und berechneten) Leistung und der später tatsächlich messbaren Leistung von sanierten Gebäuden beobachtet werden können. Dieser sogenannte Performance Gap (Leistungslücke) wird vielfach als kritische Problematik gesehen und muss daher weiter untersucht werden. Letztlich stellt dies nämlich die energie- und kostenintensiven Sanierungsbemühungen zur Reduzierung des gebäudebezogenen Energieverbrauchs und der damit verbundenen Emissionen in Frage.

Diese Masterarbeit präsentiert in diesem Kontext eine Case Study. Für ein Mehrfamilienhaus, dass vor Kurzem einer umfassenden Sanierung unterzogen wurde, werden die Energiekennzahlen der Wohneinheiten detailliert untersucht und auf eine Ablesbarkeit des Performance Gaps hin untersucht. Die Wohneinheiten des Gebäudes unterscheiden sich (naturgemäß) in Ausrichtung und Lage im Gebäude, der Anzahl der BewohnerInnen und deren Biografien. Um eine umfassende Studie über die thermisch-energetische Performance des Gebäudes und seiner Wohnungen durchführen zu können, wurden verschiedene Daten erhoben. Diese umfassen die Grundrisse im Originalzustand, die Gebäudesanierungsplanung, entsprechende Prüfberichte, und damit verbundene Energieeffizienzberechnungen sowie die Energierechnungen der BewohnerInnen. Basierend auf diesen Daten könnte ein Leistungsvergleich zwischen vor- und nach- der Sanierung durchgeführt werden, einschließlich eines Vergleichs zwischen dem tatsächlichen Energieverbrauch und der (ursprünglich) prognostizierten Leistung. Unterschiede zwischen

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erwarteter und tatsächlicher Leistung wurden analysiert und mögliche Gründe für diese Abweichungen untersucht. Beim vorliegenden Gebäude konnten in einigen Wohneinheiten signifikante Unterschiede zwischen geplanter/simulierter und erreichter Performance-Verbesserung vorgefunden werden, mit einer durchschnittlichen Abweichung von 51%, die bei den Ausreißern bei 12% bis 72% reicht.

Keywords: Performance Gap, Vergleich vor- und nach- der Sanierung, Energieausweise, dynamische Gebäudesimulation, Gebäudesanierung

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ABSTRACT

It is common knowledge that currently the built environment is responsible for a major share of both energy consumption and greenhouse gas emissions. Thus, in recent years the building regulations were tightened in view of energy consumption thresholds of buildings. Such regulations target new buildings and buildings yet to be designed, planned, and built. Given rather low new-building-rates, the building stock needs to be addressed as well to reach climate goals and mitigate the effects of climate change. Thereby, building retrofit is considered as a key activity for lowering energy demand and greenhouse gas emission of existing buildings.

From a technological perspective, building retrofit is regarded as non-complex activity: Regularly, additional insulation on building envelope components and/or replacement of components that do not fulfill energy-saving requirements is conducted. Both normative calculation and dynamic simulation can be used to assess the impact of retrofit measures onto different key performance aspects of buildings. However, past studies showed that in many cases gaps between the expected (and calculated) performance and the monitored performance of buildings after retrofit can be observed. This so-called performance gap needs to be studied furtherly, as it severely questions the energy- and cost-intensive retrofit efforts that are conducted to reduce building-related energy consumptions and emissions.

This thesis focusses on a pre- and post-retrofit comparison of the energy demand of a set of residential units in a multifamily residential house. The residential units differ in orientation and position in the building, the number of occupants and their biography. To be able to perform a comprehensive study of the performance of the building and its flats, different means of data were obtained. These encompass the building plans in the original state, the building retrofit planning and connected energy performance calculations as well as occupant's energy bills of different years. Based on this data, a performance comparison between pre-retrofit and post-retrofit state could be carried out, including a comparison between monitored energy consumption and the projected performance (based on energy certificates and dynamic simulation). Differences between expected and monitored performance were analyzed and potential reasons for these deviations were examined.

Keywords: performance gap, pre- and post-retrofit comparison, energy certificates, dynamic building simulation, building retrofit.

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1 INTRODUCTION

The title of this master thesis implies the scope of this contribution in comparison of energy consumption data pre- and post-retrofit of a specific residential building. For this purpose, different means of data acquisition have been deployed. These encompass the collection of energy bills of the occupants (pre- and post-retrofit), the previous state of the building as illustrated in the original plans, the retrofit planning conducted by an architect as well as proposed and projected energy certification calculations. Moreover, both normative calculation and dynamic simulation has been utilized as tools to assess the building and its residential units. In detail, energy simulation has been used for determining potential reasons for observed improvements (or degradations). As such, simulation enables us to see how consistent changes to our assumptions will bring us to identifying the extent of a probable energy performance gap. The goal of these efforts is thus not necessarily to reach the real consumption values by simulation calibration, but rather to observe the magnitude of various factors affecting the energy performance following the refurbishment. In this context, the present contribution resembles a case study with strong focus on sensitivity analysis that potentially provides insight onto influencing factors of the performance gap.

In the Motivation Section (Section 1), this work commences with a couple of renovation projects analyzed around the EU. Followed by a description of the most recent studies within the field of user behavior, building energy consumption, and energy performance gap as the scientific Background for this thesis. The methods used in data collection, evaluation, and simulation are described in the Methodology Section (Section 2), providing an explanation of the input data and adjustments made to the simulation procedures (Adjustments 1 + 2 + 3). The simulation results and their comparison with the real consumption are described in Section 3. The subject of thesis limitations and future research is concluded in the 4th Section of this work.

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1.1 Overview

Buildings (including both households and commercial spaces) account for approximately 40% (Residential: 26.3%) of the total energy consumption in the European Union (European Council 2020), over one-third of the final energy consumption globally and an equally important source of CO_2 emissions (36% in the EU). It is indisputable that in the pursuit of reducing the carbon print of buildings, one of the most consequential factors is reducing the energy required to heat and cool down the buildings, it is therefore essential to convince the involved stakeholders to invest in improving the energy efficiency of buildings.

In the capital city of Austria, Vienna, the advocate role in renovating and reducing the overall energy demand of the residential fond on a municipal level is fulfilled by the institutions of *Wohnfonds Wien* and *Wiener Wohnen*. The influence and importance of these organizations in achieving an improved energy performance in Vienna is not exaggerated, considering that the approximately 13 million square meters of the offered social housing is home to 500.000 people (and thus over 25% of the city's population) (Stadt Wien, wienerwohnen.at 2018). In recent years, the municipality of Vienna and the Government have displayed a financial readiness and motivation to improve the technical performance of its building stock, by simultaneously providing subsidiary grants and harmonising the strict building regulations within this scope. The more obvious step observed in local renovations is the thermal insulation of the objects and bettering their aesthetics.

The *Am Freihof 33*, which is the location of the building analysed in this project, is a renovation *archetype*, a renovation in which each inhabitant has expressed an improvement of their well-being (certainly also in correlation with their reduced expenses).

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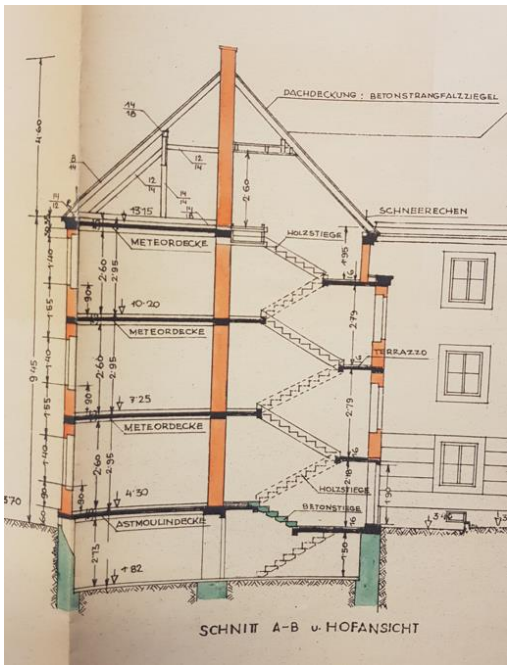

Figure 1 As-built documentation (1951) - Section view of the Am Freihof 33

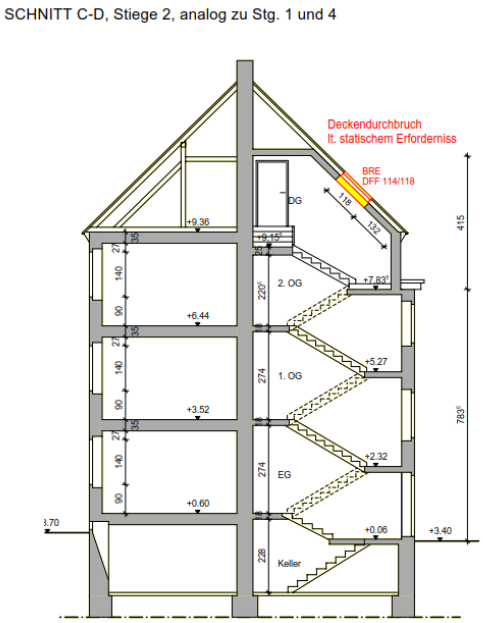

Figure 2 Extract of the application plan (2015) - Section view (renovation measures)

Nevertheless, a deeper analysis, that could quantify the exact amelioration following the renovation, has not yet been conducted. As such, this building complex provides an excellent opportunity for a scientific study. A big advantage of conducting such a study in academic context is the strict neutrality toward all stakeholders, a potentially fact-based and non-biased result analysis, when conducted scientifically rigorous. In a broader context, such case studies of specific buildings might be beneficial in better understanding potential flaws in retrofit planning and building operation, that would counter interdict with the energy saving and emission reduction measurements.

The pre- and post-retrofit status has been analysed by comparing the real consumption data (energy bills) before and after the renovation was undergone. This information – received from the building occupants, has been compared to the results of the simulations executed with a dynamic thermal simulation environment (Energy Plus), as well as with the data from the Energy Certificates elaborated using ArchiPhysik.

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1.2 Motivation

Although EU-member states are making investments in implementing strategies towards increasing the energy performance of the building fond, there is an existing gap of knowledge about the actual energy savings of renovation measures. This speculation is also confirmed by different research efforts, such as a study carried out in the Netherlands (Majcen et al. 2016), where data regarding the state of social housing, including energy performance, have revealed that there is more information about the thermal measures taken in the housing stock but not on their effectiveness to achieve energy savings.

A comparative analysis has been carried out for a deep energy renovation in Denmark (Thomsen et al. 2015) – a €6.6 million subsidized rehabilitation of a 5293 m² residential building (year 1969) in the village of Hvalsø, which resulted in an overall energy bill reduction of 31% (€ 8.000 yearly savings in electricity, and €22.280 in heating), high approval ratings of the indoor air quality among the users (questionnaire results) but a 12.9% increase in the rent.

To this end, the City of Vienna continuously invests in residential renovation every year. Around 200 million € are made available annually from funds from Vienna's housing subsidy. There are currently (year 2021) 247 residential buildings with more than 17.300 apartments in the entire city area under renovation. Another 185 residential buildings with around 13.600 residential units are being audited right now (Stadt Wien, wohn-service Wien 2021). Nevertheless, during the thesis elaboration process, several challenges have been established when accessing consumption data of refurbished buildings, making it demanding to determine the real technical, financial, and social impacts of the refurbishments.

Several studies are providing an insight into the factual representation of the renovation improvements. In the context of the proposed master thesis topic, it is of interest to follow the good practice by carrying out a comparison between the energy consumption registered before and after the retrofit. It is assumed that the performance indicators have improved following the upgrade of the building envelope. Furthermore, the investigation is intended to determine whether the renovation has reached a technical and financial feasibility. It is therefore of interest to identify the factors affecting the extent of the performance gap, which one of the main indicators affecting the potential of energy reduction in buildings.

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The premise of the present study is therefore to:

1. Quantify the energy improvements in a typical renovation implemented by the municipality of Vienna (For the building complex *Am Freihof 33*, which has been renovated between 2015 – 2016).
2. Deploy dynamic thermal simulation to assess the effect of the envelope improvements on the overall energy demand.
3. Identify the extent of the performance gap observed in the retrofit project (contrast between the real consumption data vs. simulated heating demand).

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1.3 Background

This section includes an evaluation of the previous efforts made in assessing the observed reduction in energy consumption; carried out primarily through:

1. analysing studies within the proposed topic
2. analysing the trends in understanding the pattern of users' behaviour in buildings
3. identifying the most impactful forms of reducing demand and
4. the impact of the energy performance gap

Needless to say, any literature review in the field of the performance gap and building's energy performance can only remain an incomplete convolute, if not specifically addressed as meta study, given the number of publications every year. However, the studies described in the following section can be considered as path-breaking for the scientific community and as providing fruitful background information for the present case study and thesis.

1.3.1 Studies on user behaviour and diversity

In a study conducted by Mahdavi and Tahmasebi (Mahdavi et al. 2015), the following is stated: "*Given the impact of occupants on building performance, modelling occupants' presence and behaviour is one of the critical topics in the studies pertaining to building performance simulation*". Following this idea, it is safe to say that the occupants' behaviour and diversity play a significant role in the determination of the heating or cooling demands, yet there are a considerate number of methodologies developed to quantify the effect of occupancy in a building.

Duarte (Duarte et al. 2013) categorises the occupancy diversity methods into *Deterministic and Stochastic*; mentioning as a deterministic approach the 2010 study of Davis and Nutter (Davis et al. 2010), which directly targets the occupancy, and who *reported on building occupancy data through the use of building security cameras, doorway electronic counting sensors…and manual tabulation*; on the other hand pointing out Mahdavi's (Mahdavi et. al. 2015) approach as focused on the interactions of the users with their environment, a study implemented by installing sensors which monitored the relative humidity, temperature, air velocity, illuminance, global irradiance etc. in correlation with occupancy.

In the context of this case study, the focus was made on simulation-based determination of energy performance gap behavior. There was no monitored data about occupant's behavior available. Therefore, the standard occupancy profiles from

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the Austrian Norms and ASHRAE Handbook were considered as basis. Moreover, some of the occupants provided qualitative descriptions about their occupancy behavior.

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1.3.2 Studies on building energy consumption

There are a few studies pertaining to a comparison of building performance level's before and after renovation and including projected versus measured performance. These studies regularly show similar conclusions, slightly differing due to renovation measures and possible national particularities and/or tenants' awareness.

For instance, Hamburg (Hamburg, et al. 2020) analysed the reached energy performance of a nearly Zero Energy Building (further abbreviated as nZEB) renovation in the city of Tallin, Estonia. The case study building showed a rather impressive reduction of the measured heating energy demand by 76% after renovation (from 168 kWh.m²a to 41 kWh.m²a). However, this performance still was 1.8 times higher than the projected heating energy use that was envisioned during the planning process via dynamic thermal simulation (23 kWh.m²a).

Some studies indicate that projected energy levels of many renovated buildings are exceeded by a factor of 3 despite the endorsement of green building regulations and the incorporation of energy-efficient technologies and underline the existence and relevance of the "performance gap". (Zou et al. 2020).

A study dealing with 11 renovated multifamily houses in Poland (Cholewa et al. 2020) stated the following: *the actual energy savings range between 8.8% and 74.8% of calculated energy savings, depending on the different renovations. The actual payback time for the analysed modernization actions was longer than the calculated one, ranging between 3.1 and 104.8 heating seasons.* This study was based on a comparison between monitored energy consumption and energy demand estimates made by energy auditors in the planning process. The considerable range of deviation that can be found in this study led to the conclusion that the most feasible renovation scenario for each building should comprise intelligent and holistic strategies. As an example, they stated the need to perform a post-renovation hydraulic balancing of the heating system after the thermal improvements to the envelope. The hypothesis that renovated buildings show performance values that deviate from the envisioned performance improvements was also confirmed in the paper. Moreover, despite similarities in performed retrofit measures, the deviations showed different extents.

De Wilde stated in his 2014 study (de Wilde 2014) that, *"within the building industry, there is an increasing concern about a mismatch between the predicted energy performance of buildings and actual measured performance, typically addressed as the performance gap"* Furthermore he has investigated the performance gap in buildings by discerning three main types of gaps: (1) between first-principle

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predictions and measurements, (2) between machine learning and measurements, and (3) between predictions and display certificates in legislation.

A performance gap will vary from one building to another; in many cases, there will be a combination of several issues, some being indicated below.

During design phase:

- Miscommunication about performance targets
- Unclear prediction of the building's function
- Oversizing of HVAC systems
- Underperformance of equipment
- Unreliable predictions (incorrect methods of simulation, energy certificates)

During operation:

- Changing weather conditions
- Occupancy schedules, internal heat gains, plug loads
- Occupant behaviour
- Lack of control settings (e.g., thermostats, facility management)
- Lack of routine POE (Post Occupancy Evaluation)

There is currently an abundance of opinions regarding ways to curb the performance gap, focusing mainly on the need of a coordinated approach to better the comprehension of the factors generating the disparities. More effort must be done in collecting, monitoring, and analysing the data. De Wilde considers that the most promising solution to extensively study the performance gap is to study various buildings based on the same design. Alternatively, he suggests a deep case study, including model calibration, which would explore and quantify the factors that cause the performance gap in one specific instance. Furthermore, one could look at larger sets of buildings, hoping to identify homogenous sub-sets with very similar performance.

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1.3.3 Studies on the energy performance gap

The differences between the expected vs. the observed energy consumed in buildings are usually associated to the buildings' geometry, envelope construction, systems, and weather conditions. In practice, considerable attention is offered to the above-mentioned factors due to their quantifiable nature. Nevertheless, studies regarding the energy performance gap (further abbreviated as EPG) have been intensively published in the first and second decades of the 21st Century, predominantly arguing for a more complex approach to the role of the occupants and their effect on a building's energy consumption. A culmination of all these efforts can be found in a recent meta study by Mahdavi et al. (Mahdavi et al. 2021) who have analysed the extent of the "myth or reality" in the context of how much a user's behaviour will affect the EPG. Most of the studies in EPG have been found to be in Europe (78%); out of which, about 60% are assessed residential buildings, indicating an interest in such purpose of buildings. "*For retrofit projects, this so-called performance gap is split into a prebound and rebound effect…The prebound effect describes the difference between the predicted and actual energy use before the renovation measures and the rebound effect denotes such difference after completion of the project.*", this "rebound effect" is a very probable cause for unexpectedly high energy consumption in retrofitted buildings, yet a proper identification of such an effect would require a thorough analysis of the indoor thermal conditions prior to the renovation works.

An essential step in isolating the contribution of occupant related factors to EPG is the correction of weather data. Almost one third of the studies (31%) have monitored the outdoor weather conditions to normalize the measured energy use data. This so-called "normalization", *with regard to weather conditions enables a proper comparison of predicted and actual energy geometry, construction and occupancy patterns when comparing before-after energy.* (Mahdavi et al. 2021).

Standard assessment procedures (abbreviated as SAPs), dynamic solutions or database solutions are the basis of predicting energy use. The authors mention that SAPs are either based on national standards or general assessment tools. The building simulation in this case study has been performed using Energy Plus, which offers energy prediction capabilities with high temporal and spatial granularity. In the paper it is mentioned that *"for multi-residential buildings and social housing, studies varied in their spatial granularity with equal shares between apartments and the overall building with one study investigating individual rooms"*.

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In the context of this master thesis, each room has been represented as a separate thermal zone in the process of energy demand simulation, depicting a more accurate result due to the more detailed spatial granularity (vs analysing entire apartments as one thermal zone).

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2 METHODOLOGY

2.1 General approach

This chapter describes the processes of collection and interpretation of the energy consumption data, along with identifying the effect of the heating system efficiency and the extent of DHW utilization on the space heating energy demand. Further on, a clarification has been presented with regard to how simulation scenarios have been adjusted (e.g., through benchmarking, normalization) to identify the potential of the Energy Performance Gap. With that in mind, this work presents the findings of on-site procedures and three phases of building simulation adjustments (Adjustment 1, 2, and 3).

The underlying workflow in the implementation of the proposed analysis has been structured in the following sequence:

1. Collection, graphical representation, and interpretation of the energy bills.
2. Interviewing the users of the building.
3. Identification of the exact alterations made to the building envelope during the renovation (structure, U-Values, choice of materials).
4. Producing an accurate illustration of the real building conditions during Energy Plus programming.
5. Continuous adjustments (i.e. educated guesses) of the impacting factors on the consumption numbers:
    - Benchmarking of DHW consumption
    - Benchmarking the heating setpoint, internal gains and schedules conforming to the EN Standards, ÖNORM B-8110-3:2020-06 and ASHRAE Handbooks
    - Normalization of weather information
    - Calibration of the infiltration/natural ventilation (ACH).

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2.2 Case study building: Am Freihof 33

In order to identify a potential building for the assessment of how effective implemented retrofit measures are, an external cooperation has been established with the *Wiener Wohnen.* This organisation possesses a sizeable database of retrofitted households; can initiate contact with the inhabitants of any chosen building; and has agreed to provide technical as well as financial data behind the renovation projects of interest.

As previously mentioned, in the EU there is currently more information about the thermal measures taken in the housing stock but not on their effectiveness to achieve energy savings. This is also the case for Austria, where gaining access to consumption data for research purposes is restricted by the lack of cooperation from the majority of (individual) occupants or for data privacy protection reasons. It was of interest to identify buildings with tenants willing to contribute to this project.

Therefore, the *Wiener Wohnen* representatives have proposed to assess the renovation of the building located on Am Freihof 33 street – a residential house comprising 27 apartments, built in 1951 as part of the Gemeinde Wohnbau in the 22nd district of Vienna. The building has a basement floor, ground floor, 2 upper floors, as well as a non-inhabited roof floor.

Table 1 Building Characteristics: Am Freihof 33

Main characteristics: Am Freihof 33 building	
Year of construction	Y.1951
Nr. of apartments	27
Nr. of Storeys	5-Storeys with Basement and Roof
Total useful area	1,348.89 m²
Heating energy source	Natural gas
Heating Energy Demand (pre-retrofit)	HWB = 202.78 kWh.m²a

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Figure 3 View of the courtyard of the Am Freihof Building (picture taken before renovation)

Figure 4 View of the courtyard of the building Am Freihof 33 (Picture taken after renovation by the author in 2019)

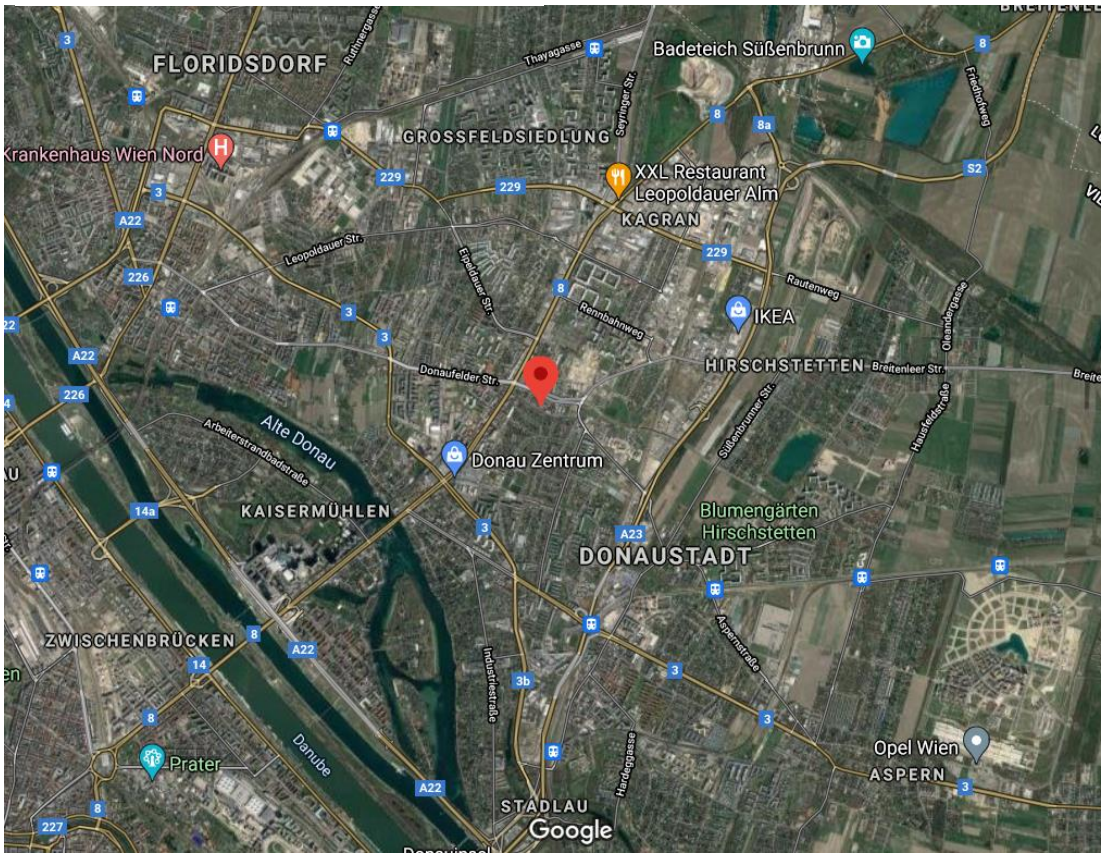

Figure 5 Google Maps, Vienna Austria: the location of the Am Freihof 33 building

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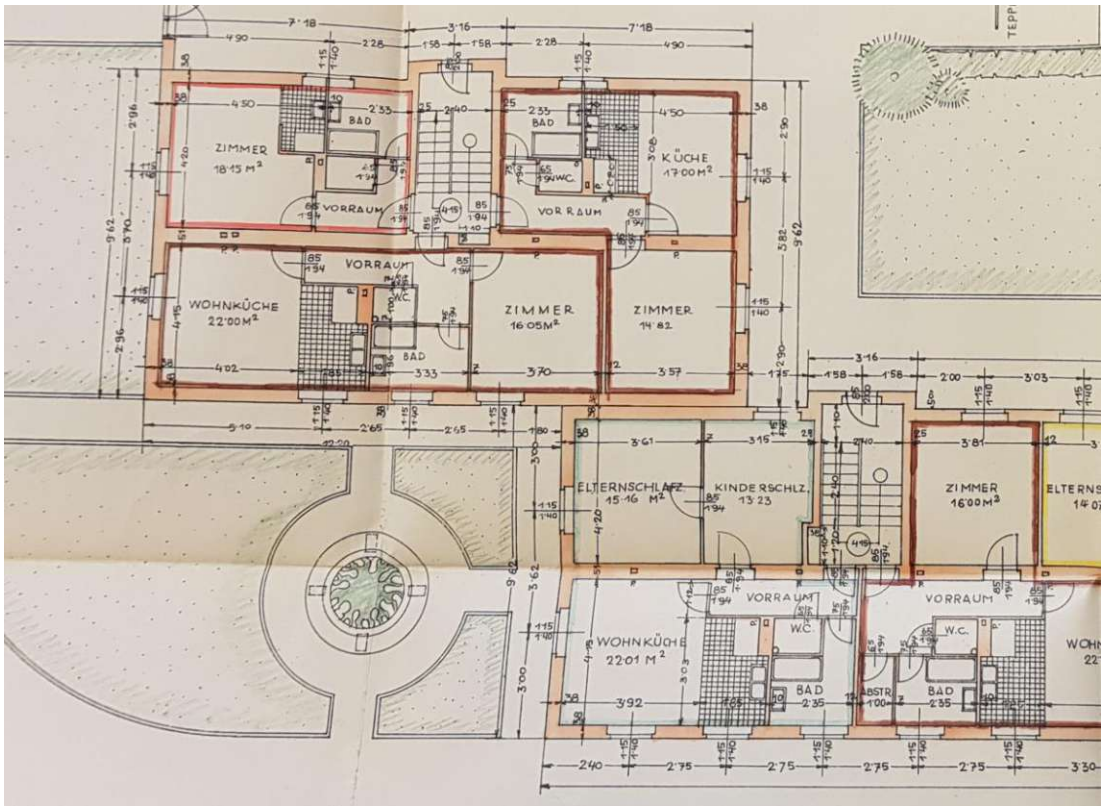

Figure 6 Ground floor plan of the Am Freihof building (part 1/2)

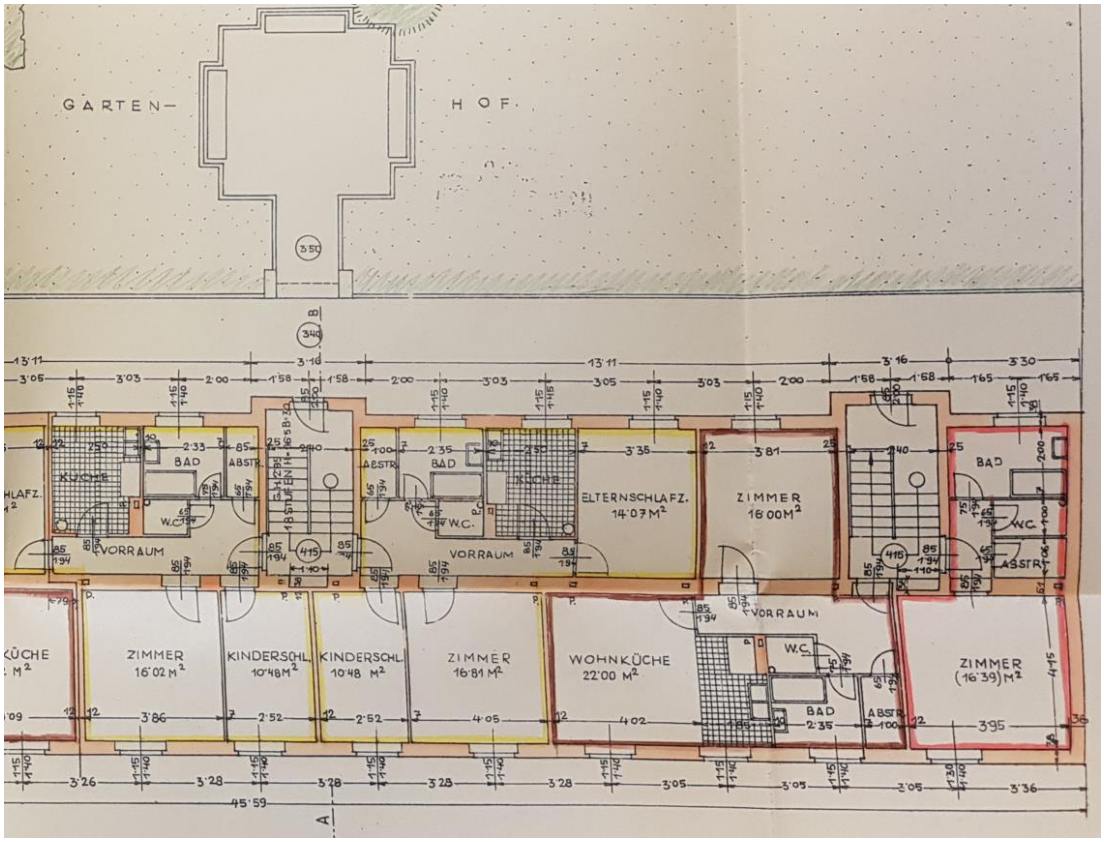

Figure 7 Ground floor plan of the Am Freihof building (part 2/2)

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As a result of the renovation solicitation submitted in the name of the inhabitants, the municipality has ruled to fund a retrofit of the building as stipulated in the Renovation Order (Sanierungsverordnung) LGB1.Nr. 2/2009 idF. 27/2009. The law qualifies applicants for an aesthetic and thermal retrofit of the building envelope.

The tenant arbitration board's decision entailed the office of Architektin DI Vera Korab ZT GmbH, as the authorized supervisor of the retrofit project. The task was to improve the energy performance of the building by insulating the facades, replacing the windows, and executing the necessary maintenance works.

Table 2 House Renovation and Maintenance works: Am Freihof 33

House renovation and maintenance works: Am Freihof 33	
Authorized construction supervisor	Architektin DI Vera Korab ZT GmbH
Renovation period	2015 – 2016
Thermal insulation (Th.ins.) of the Facades	16 cm EPS-F
Th.ins. of the Firewall	16 cm Mineral wool
Th.ins. of the roof floor	20 cm Mineral wool
Installation of Thermal Insulation Windows	Wood-Alu, U-Value = 1.10 $W.m^{-2}.K^{-1}$ (95% of the windows are to be replaced)
Heating energy demand (post-retrofit)	HWB = 37.6 $kWh.m^{-2}.K^{-1}$
Cost of Renovation	€ 647,732.75

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The works carried out during the renovation have shown an improvement of the thermal performance of the building envelope, seen through the reduction of the U-values of the new constructions compared to the old ones.

Table 3 Thermal Conductivity Values. Pre- and Postretrofit. Source: Technical Documentation

Building Envelope Structure	**Abbr.**	**Heat transmission coefficient [W.m^{-2}.K^{-1}]**	
		Before Renovation	**After Renovation**
External wall 38cm	BT1	1.22	0.17
External wall 25cm	BT2	1.63	0.18
Floor to heated basement	BT3	1.57	0.31
Ceiling to unheated attic room	BT4	1.68	0.18
Fireproof wall 25cm	BT5	1.63	0.18
Fireproof wall 38cm	BT6	1.11	1.11
Wall to unheated attic room 25cm	BT7	1.49	0.32
Wall to unheated attic room 12cm	BT9	2.13	0.33
External wall Dormer wall	BT10	1.63	0.22
Roof slope Dormer	BT11	0.47	0.20
Ceiling to attic space	BT12	1.3	0.20
Staircase roof	BT13	0.47	0.31

According to the energy certificates provided by the office of DI Vera Korab ZT GmbH, the renovation should theoretically achieve an ambitious energy labelling level, where the reduction in the heating energy demand is about 80%.

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Energy labelling scale	Energy Consumption	Expected Frame [kWh.m^{-2}]
A++		10
A+		15
A	37,60 (1) kWh/m.-2.a	25
B		50
C		100
D		150
E	202,78 (2) kWh/m.-2.a	200
F		250
G		>250

Figure 8 Energy labelling scale before and after renovation (Source: Documentation from DI Vera Korab GmbH)

(1) Energy label after Renovation
(2) Energy label before Renovation

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2.3 Data collection

The motivation behind involving certain actors was to gain sufficient information for an in-depth analysis and simulation of the energy consumption. The following stakeholders have been instrumental in the realisation of the work.

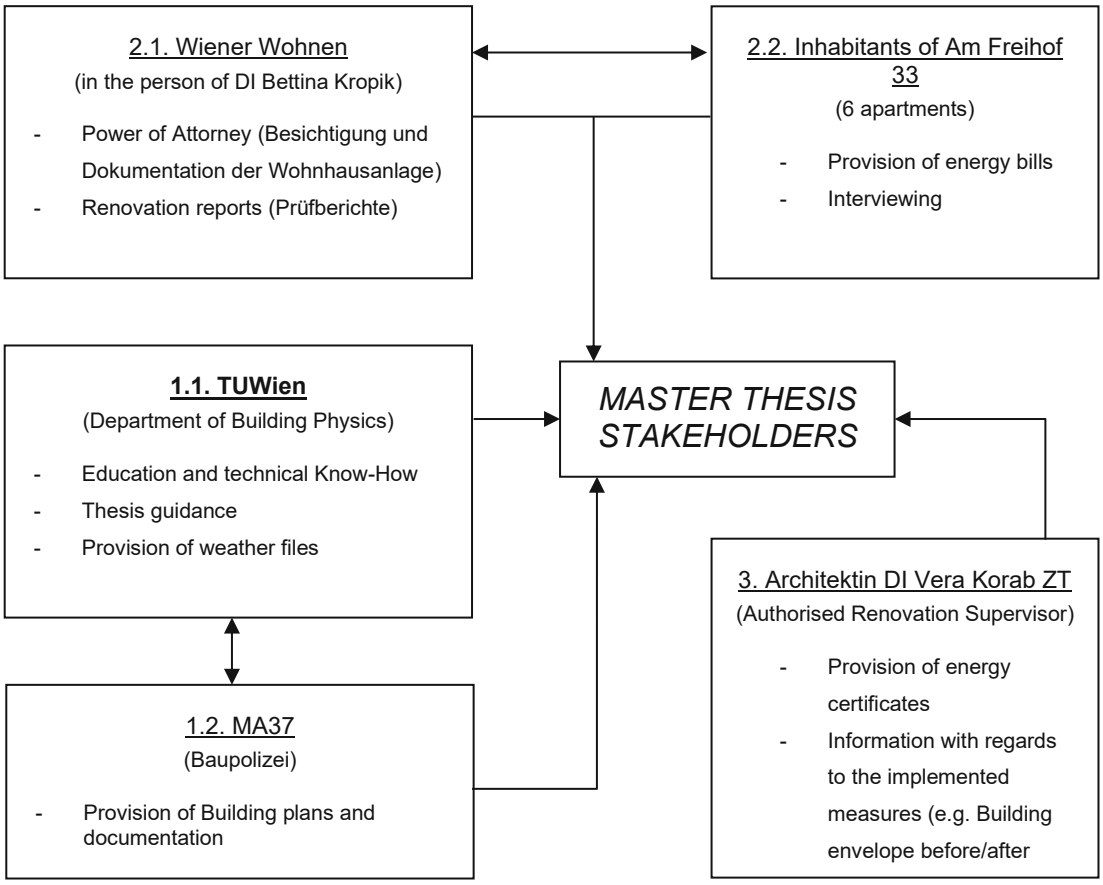

Figure 9 Primary Project Stakeholders

All the building plans have been extracted from the MA37 *Baupolizei* database, which is a Viennese municipal department in charge of storing all the data in relation to new construction developments and renovations. This documentation has been attained through an academic inquiry arranged by the Department of Building Science and Technology at the TUWien.

Elaborating simulations was feasible with the information provided by the Architecture Studio of Ms. DI Vera Korab. The gained information concerning the building envelope and the retrofit approach have been crucial in corroborating the Energy Plus files.

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The energy bills for the period before and after renovation have been collected on site during numerous interviews with each participating tenant. Out of the 27 Apartments, 21 were inhabited at the time of data collection. The tenants in 6 apartments have agreed to provide the consumption bills before and after renovation, which constitutes 30% of the occupancy. The electricity and gas is supplied to 5/6 apartments by *Wien Energie*, where one user is a client of *GoldGas.*

Table 4 Am Freihof 33: Participating apartments

Apartment	Net Floor Area [m²]	Owner	Occupancy [Persons]	Possession of Energy Bills [Year]
S.1.9	27.96	N/A	1	2013 - 2019
S.2.3	54.63	Hr. Lembcke	1	2014 - 2018
S.3.6	64.68	Fr. Jeschoffnig	1	2005 - 2019
S.4.4	54.38	Hr. Minhas	4	2017 - 2019
S.4.5	28.17	N/A	1	2019
S.4.6	54.38	Fr. Cusi	4	2014 - 2017

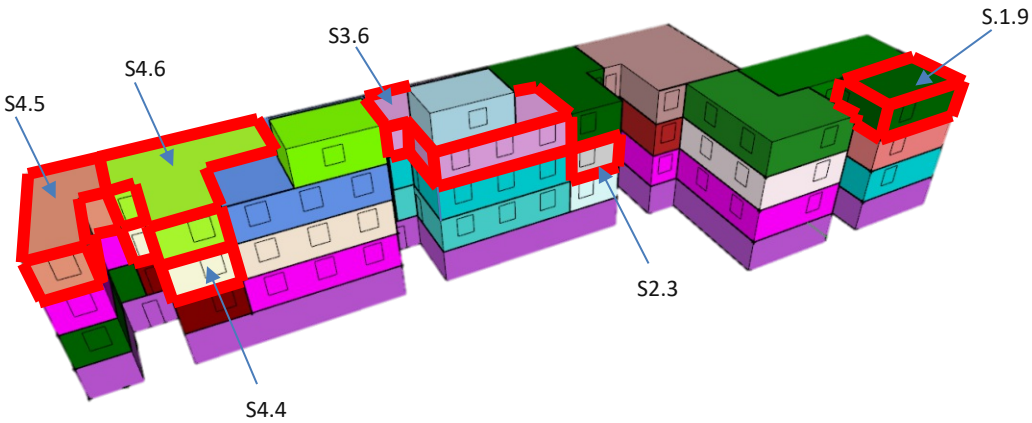

Figure 10 Illustration generated through SketchUp – representation of the apartments' location

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2.4 Energy bills screening

The heating system in the Am Freihof 33 building was not subject to refurbishment during the last renovation. It is functioning on the base of natural gas supplied to condensing boilers in each residential unit, which generate both the hot water required in the household and the heating water for the heating circuit. The schematic below illustrates how the combi-system is used as a space heating system that produces heat through the combustion of gas.

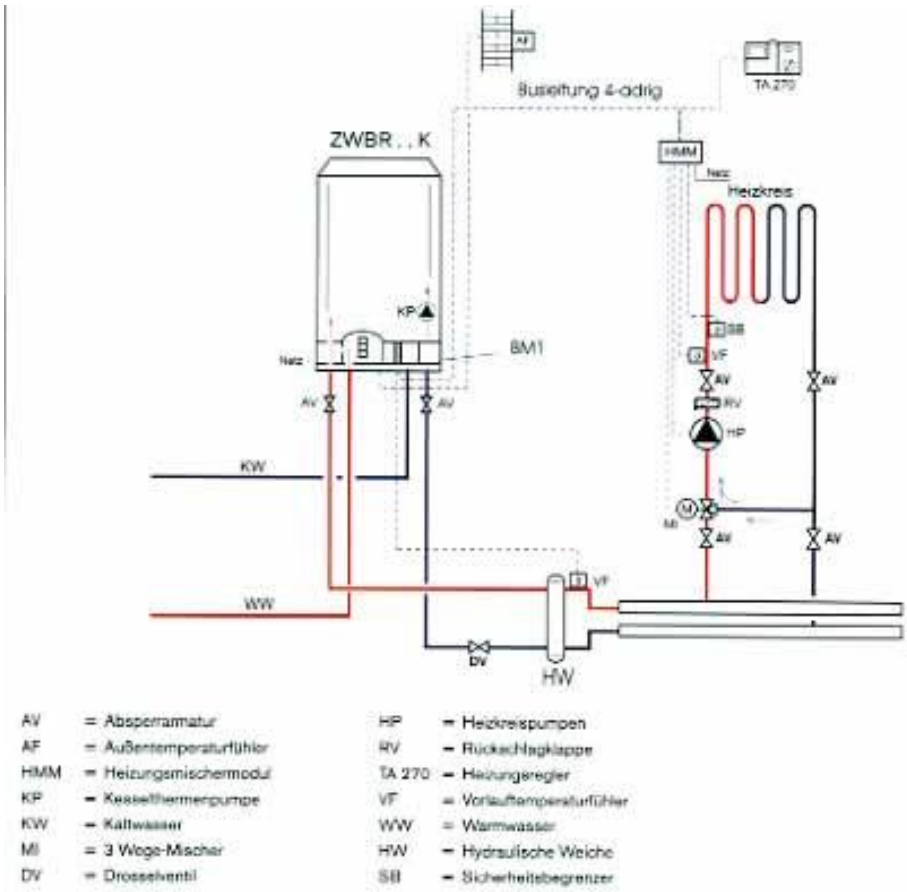

Figure 11 Schematics of the combi-heating system found in the case building.

In principle, the heat contained within the combustion gases is captured in the system and used to preheat the cold water through a heat exchanger. Successively, the circuit supplies the radiators in the apartments, at the same time generating hot water for the tapping points. Such boilers do not need a buffer storage and are according to the manufacturers, whose products are installed in the evaluated apartments, up to 99% efficient (Viessmann 2021).

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The energy supply and meter reading are carried out by the city-owned Wiener Netze company. When checking the consumption data, it is important to observe if the readings are provided with the letter **Z** in front of the metering number, which in Austria stands for *Zählerablesung durch Wiener Netze* (translated as counter reading directly from Wiener Netze), this value represents the exact amount of consumed energy. The Wien Energie bills also indicate the consumption in kWh converted for the thermal capacity of the supplied gas (Factor 10.709).

Detailrechnung Gas

Tarif: Gas OPTIMA, Netzebene 3
Zählergröße: G0006
Zählpunkt: AT9000590000000000000000000637505

Ablesedaten
Zählernummer: 1804399

Zeitraum	Zählerstand alt		Zählerstand neu		Verbrauch	Faktor	Verbrauch
20.01.2016 - 11.01.2017	Z	28.502	Z	28.901	399 m³	10,709	4.273 kWh

Z...Zählerablesung durch Wiener Netze

Figure 12 Heating energy bill from Wien Energie (photographed by the author, provided by one of the occupants)

2.5 Domestic hot water consumption

The data in the energy bills of the case study building does not provide a separation between the gas demand for space heating and DHW consumption, a reliable assessment requires a detailed analysis of the domestic hot water usage profiles. The DHW will account for a significant share of the final energy demand in a building. Simply put, to assess the energy required needed for space heating it is important to subtract the DHW consumption from the total heating energy use.

Fuentes (Fuentes et al. 2018) describes statistical methods to review the hot water consumption profiles in different types of buildings based on several international standards. His findings have been taken as a reference point in determining the DHW demand in the case study.

In addition to Fuentes's observations the process of benchmarking the DHW demand in the Am Freihof building has included analyzing the Austrian Norms (ÖNORM B8110), the German Standard for "Heat pumps with electrically driven compressors – testing, performance rating and requirements for making of domestic hot water units" (DIN EN 16147:2012-06) and the Annex 42 of the International Energy Agency (DHW consumption values for Germany).

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Table 5 DHW daily loads according to the ANNEX 42 of the International Energy Agency Report (source: Fuentes et.al. 2018 paper, Table 5)

Country	Daily DHW consumption per household (l/day)	Daily DHW consumption per occupant (l/occupant.day)	Daily DHW energy usage per household* kWh/day
Canada	236–303	94	12.3
USA	202–250	40	5.22
Switzerland	138	55 at a 50 °C rise	7.18
Finland	135	43	5.61
UK	102–117	20–39	3.85
Germany	160	64	8.36
France	1.74 per m^2 (at a 30 °C rise)	69.6	9.1
Spain	75	30 (at 60 °C)	3.92
Portugal	100 (at a 45 °C rise) (apartments)	40	5.23

Table 6 DHW Daily loads and draw-offs in different international standards (source: Fuentes et.al. 2018 paper, Table 2)

Standard	Schedule types	Number of draws	Daily load (kWh/day)	Average (MJ/draw)
Europe				
EN 16147:2011	S	11	2.10	0.69
	M	23	5.85	0.92
	L	24	11.66	1.75
	XL	30	19.07	2.29
	XXL	30	24.53	2.92
Australia and NZ				
AS/NZS 4234	1	8	6.25 to 15.8	Varies with season
Canada				
CSA C74503:2003	Standard	6	12.1	7.28
Japan				
JIS C 9220:2011	Std Winter	51(56)	16.276	1.149
	Std intermediate	51(56)	12.076	0.852
	Std Summer	51(56)	8.401	0.593
	Small Winter	31(34)	9.927	1.153
	Small Intermediate	31(34)	7.365	0.855
	Small Summer	31(34)	5.124	0.595

The presented Table 6 and Table 7 summarize the statistical DHW consumption data in certain international norms. It was of interest to observe the categorization

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proposed by the European Standard EN 16147:2011, which defines 7 schedule types (5 of which are demonstrated in the table) i.e., consumption profiles of users; and to use this approach in assessing the hot water consumption in the case study.

2.6 Simulation process protocol

The purpose of this chapter is to indicate the mechanism used to rectify the correctness of the simulation procedure, which has been formally represented in three steps, accompanied with screenshots.

The available building plans have been drawn in the SketchUp 3D-computer modelling application and imported into EnergyPlus, using OpenStudio Model. EnergyPlus is a whole building energy simulation program that engineering and architectural professionals use to model the energy consumption for heating, cooling and ventilation of buildings, whereas OpenStudio is an open-source software development-kit used as a platform for building energy modelling. The process described below can be considered a protocol in creating a building simulation.

1. Building documentation analysis
   a) Analysing the MA37 building plans
   b) Setting up the shape and envelope structure for SketchUp implementation
   c) Defining the differences in construction pre- and post-retrofit (DI Vera Korab)

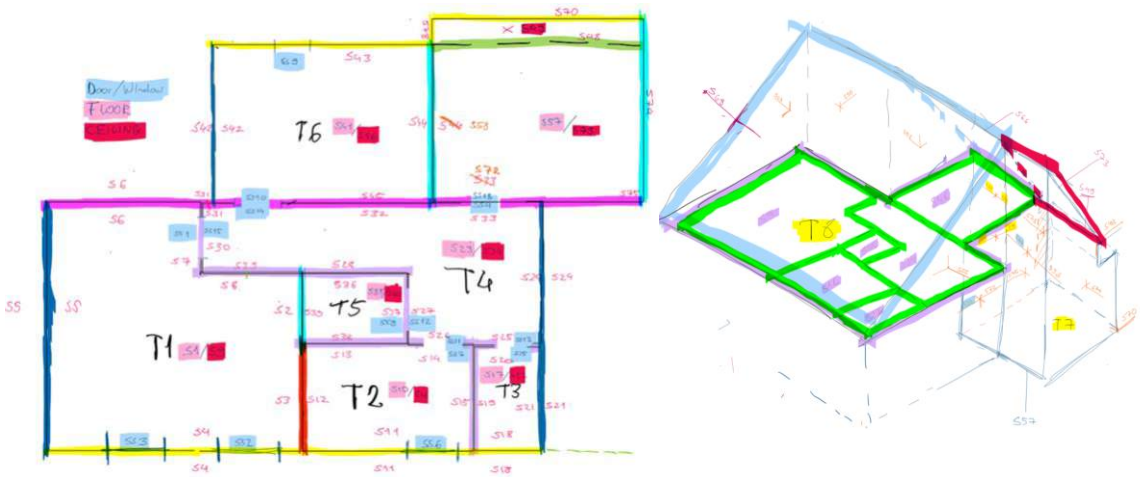

Figure 5: Images of the sketches made during the plan analysis process of Apartment S4.6 before launching into Sketchup.

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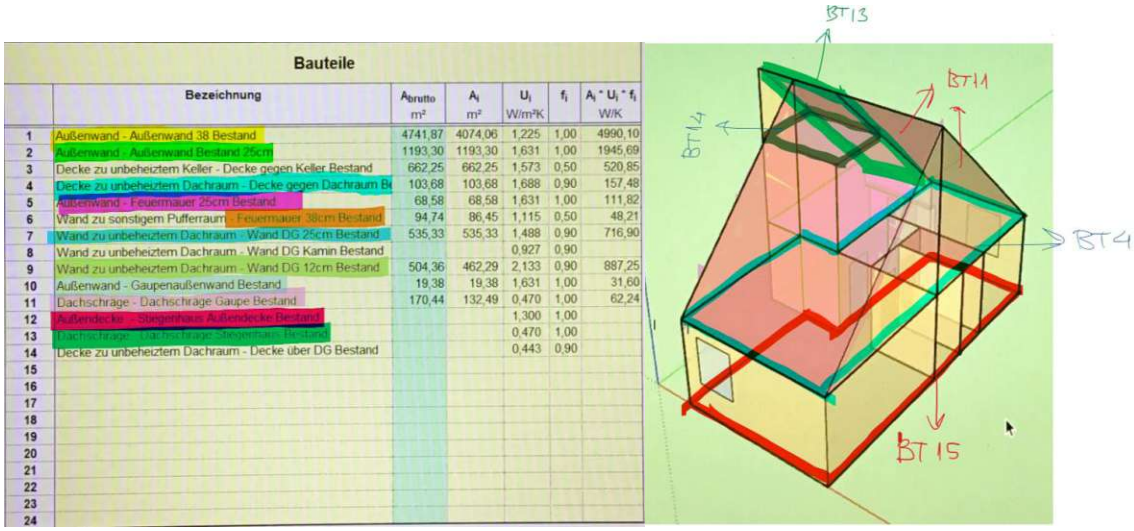
2. SketchUp and Open Studio model creation
   d) Drawing of floor plans and projection of loose geometry (windows and doors)
   e) Defining adiabatic layers
   f) Assigning a thermal zone to each room (for a thorough sim. of heat flow)



Bauteile

	Bezeichnung	A_{brutto} m²	A_i m²	U_i W/m²K	f_i	$A_i * U_i * f_i$ W/K
1	Außenwand - Außenwand 38 Bestand	4741,87	4074,06	1,225	1,00	4990,10
2	Außenwand - Außenwand Bestand 25cm	1193,30	1193,30	1,631	1,00	1945,69
3	Decke zu unbeheiztem Keller - Decke gegen Keller Bestand	662,25	662,25	1,573	0,50	520,85
4	Decke zu unbeheiztem Dachraum - Decke gegen Dachraum Be	103,68	103,68	1,688	0,90	157,48
5	Außenwand - Feuermauer 25cm Bestand	68,58	68,58	1,631	1,00	111,82
6	Wand zu sonstigem Pufferraum - Feuermauer 38cm Bestand	94,74	86,45	1,115	0,50	48,21
7	Wand zu unbeheiztem Dachraum - Wand DG 25cm Bestand	535,33	535,33	1,488	0,90	716,90
8	Wand zu unbeheiztem Dachraum - Wand DG Kamin Bestand			0,927	0,90	
9	Wand zu unbeheiztem Dachraum - Wand DG 12cm Bestand	504,36	462,29	2,133	0,90	887,25
10	Außenwand - Gaupenaußenwand Bestand	19,38	19,38	1,631	1,00	31,60
11	Dachschräge - Dachschräge Gaupe Bestand	170,44	132,49	0,470	1,00	62,24
12	Außendecke - Stiegenhaus Außendecke Bestand			1,300	1,00	
13	Dachschräge - Dachschräge Stiegenhaus Bestand			0,470	1,00	
14	Decke zu unbeheiztem Dachraum - Decke über DG Bestand			0,443	0,90	
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						

Figure 6
Left –Image of the building envelope list (DI Vera Korab)
Right – screenshot of a SketchUp implementation.

3. Energy Plus Model
   g) Checking for errors and import accuracy, including these parameters:
      a. *GlobalGeometry*
      b. *Zone* & *Zonelist*
      c. *BuildingSurface:Detailed*
   h) Adjusting *FenestrationSurface:Detailed* parameter
   i) Adjusting *InternalMass* parameter
   j) Assigning construction materials and their parameters (thermal conductivity, density, heat capacity, thickness)
   k) Adjusting *Material* parameter
   l) Adjusting *Material:AirGap* parameter
   m) Adjusting *WindowMaterial:Glazing* parameter
   n) Adjusting *Construction* parameter
   o) Defining required schedule objects (occupancy and internal heat, based on ASHRAE and Austrian Norms + Ventilation/air change)
   p) Adjusting *Field: People*
   q) Adjusting *Field: ElectricalEquipment*
   r) Adjusting *ZoneInfiltration:DesignFlowRate* parameter
   s) Setting up heating setpoints (benchmarked indicator)

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t) Programming the necessary output data
u) Choosing the relevant weather files (for the city of Vienna)
v) Simulate.

2.7 Implementation of standards in simulations

A reoccurring challenge in determining the internal heat gains and occupancy schedules is the irregularity observed in human behavior, Duarte (Duarte et al. 2013) describes the same circumstances in terms of non-residential buildings, which can be applied to residential buildings as well: *Due to the random nature of individuals' behavior and challenges accessing accurate data, current studies include the creation of deterministic schedules where a standard workday profile is the same for the whole workweek and both weekend days have the same profile. Depending on the available data, this method assumes no change in occupancy schedules throughout the year. These are referred to as deterministic models.* Consequentially the time scheduling, internal gains, and tenants' behaviors has been determined using normative assumptions, provided in the ASHRAE Standards, and the Austrian Norms; besides the estimated occupancy schedules from interviewing the tenants.

2.7.1 ASHRAE Standards

The simulations under *Adjustments 1* have been executed using the information collected during the interviewing of the buildings users, consequently the values for the internal gains have been implemented according to the ASHRAE Handbook of Fundamentals (SI). This standard indicates the sensible heat gains (in W) as a factor of occupancy and type of activities, whose determination was highly dependent on the information provided by the dwellers.

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18.4 2017 ASHRAE Handbook—Fundamentals (SI)

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

Degree of Activity	Location	Total Heat, W: Adult Male	Total Heat, W: Adjusted, M/F[a]	Sensible Heat, W	Latent Heat, W	% Sensible Heat that is Radiant[b]: Low *V*	% Sensible Heat that is Radiant[b]: High *V*
Seated at theater	Theater	115	105	70	35	60	27
Seated, very light work	Offices, hotels, apartments	130	115	70	45		
Moderately active office work	Offices, hotels, apartments	140	130	75	55		
Standing, light work; walking	Department store; retail store	160	130	75	55	58	38
Walking, standing	Drug store, bank	160	145	75	70		
Sedentary work	Restaurant[c]	145	160	80	80		
Light bench work	Factory	235	220	80	140		
Moderate dancing	Dance hall	265	250	90	160	49	35
Walking 4.8 km/h; light machine work	Factory	295	295	110	185		
Bowling[d]	Bowling alley	440	425	170	255		
Heavy work	Factory	440	425	170	255	54	19
Heavy machine work; lifting	Factory	470	470	185	285		
Athletics	Gymnasium	585	525	210	315		

Notes:
1. Tabulated values are based on 24°C room dry-bulb temperature. For 27°C room dry bulb, total heat remains the same, but sensible heat values should be decreased by approximately 20%, and latent heat values increased accordingly.
2. Also see Table 4, Chapter 9, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 W.

[a] Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, and assumes that gain from an adult female is 85% of that for an adult male, and gain from a child is 75% of that for an adult male.
[b] Values approximated from data in Table 6, Chapter 9, where *V* is air velocity with limits shown in that table.
[c] Adjusted heat gain includes 18 W for food per individual (9 W sensible and 9 W latent).
[d] Figure one person per alley actually bowling, and all others as sitting (117 W) or standing or walking slowly (231 W).

Figure 13 Representative rates at which heat and moisture are given off by human beings in different states of activity; from the 2017 ASHRAE Handbook-Fundamentals (SI), Table 1

In terms of activities, these have been directly discussed with each participating tenant and building occupancy schedules have been elaborated for the execution of simulations. This step in the project plays an important role in arguing the need of using deterministic models, mainly due to the request for objective argumentation (and not anecdotal evidence from the users) since no sensors have been installed to observe the interaction of the users with their surroundings.

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2.7.2 Austrian Standards

The referred to Austrian Standard is the *ÖNORM B8110-3:2020 "Thermal insulation in building construction - Part 3: Determination of the operative temperature in summer (parameters to avoid overheating in summer)"*. The standard stands as basis for the Adjustments 2 and Adjustments 3 scheduling concept, exemplified through the values from the following tables.

	Wohn-gebäude
$P_{BF(h)}$	W/m²
$P_{P(h)}$	
$P_{R(h)}$	
00:00 bis 01:00	1,76
01:00 bis 02:00	1,67
02:00 bis 03:00	1,80
03:00 bis 04:00	1,80
04:00 bis 05:00	2,61
05:00 bis 06:00	5,76
06:00 bis 07:00	5,09
07:00 bis 08:00	8,06
08:00 bis 09:00	6,84
09:00 bis 10:00	6,30
10:00 bis 11:00	5,67
11:00 bis 12:00	4,10
12:00 bis 13:00	3,47
13:00 bis 14:00	3,33
14:00 bis 15:00	5,36
15:00 bis 16:00	6,30
16:00 bis 17:00	7,70
17:00 bis 18:00	6,71
18:00 bis 19:00	6,26
19:00 bis 20:00	5,36
20:00 bis 21:00	4,32
21:00 bis 22:00	3,11
22:00 bis 23:00	2,70
23:00 bis 24:00	1,98

Table 9 Specific heat gains from equipment (Table 2 from ÖNORM B8110-3:2020)

	Wohn-gebäude
$V_{L(h),BF}$	m³/(m² · h)
$V_{L,P(h)}$	
00:00 bis 01:00	1,411
01:00 bis 02:00	1,411
02:00 bis 03:00	1,411
03:00 bis 04:00	1,411
04:00 bis 05:00	1,411
05:00 bis 06:00	1,411
06:00 bis 07:00	1,411
07:00 bis 08:00	1,411
08:00 bis 09:00	0,353
09:00 bis 10:00	0,353
10:00 bis 11:00	0,353
11:00 bis 12:00	0,353
12:00 bis 13:00	0,353
13:00 bis 14:00	0,353
14:00 bis 15:00	1,058
15:00 bis 16:00	1,058
16:00 bis 17:00	1,058
17:00 bis 18:00	1,058
18:00 bis 19:00	1,411
19:00 bis 20:00	1,411
20:00 bis 21:00	1,411
21:00 bis 22:00	1,411
22:00 bis 23:00	1,411
23:00 bis 24:00	1,411

Table 7 Specific hygienic air flow in naturally ventilated spaces (Table 4 from ÖNORM B 8110-3:2020)

	Wohn-gebäude
$V_{L,P(h)}$	
$V_{L(h),BF}$	W/m²
00:00 bis 01:00	3,76
01:00 bis 02:00	3,76
02:00 bis 03:00	3,76
03:00 bis 04:00	3,76
04:00 bis 05:00	3,76
05:00 bis 06:00	3,76
06:00 bis 07:00	3,76
07:00 bis 08:00	0,94
08:00 bis 09:00	0,94
09:00 bis 10:00	0,94
10:00 bis 11:00	0,94
11:00 bis 12:00	0,94
12:00 bis 13:00	0,94
13:00 bis 14:00	2,82
14:00 bis 15:00	2,82
15:00 bis 16:00	2,82
16:00 bis 17:00	2,82
17:00 bis 18:00	3,76
18:00 bis 19:00	3,76
19:00 bis 20:00	3,76
20:00 bis 21:00	3,76
21:00 bis 22:00	3,76
22:00 bis 23:00	3,76
23:00 bis 24:00	3,76

Table 8 Specific heat gains from people (Table 3 from ÖNORM B 8110-3:2020)

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2.8 Simulation adjustment scenarios

Based on the existing information with regard to the energy bills, renovation solutions and rather limited amount of data about the DHW consumption, heating setpoints and usage profiles, the main challenge was to identify suitable calibration methods and to determine a coherent representation of the performed simulations.

The process includes *156* simulations in Energy Plus, which can be divided into three phases, descriptively called: **Adjustments 1**, **Adjustments 2,** and **Adjustments 3**. The adjustments have been done to the raw data files in energy plus, it is therefore not of interest to discuss the initial simulation results.

The focus has been made on the results following the **Adjustments 3** simulations, which is a data clean-up following the benchmarking of inputs, these adaptations were necessary as a consequence of more or less disputable results of the initial two adjustments (**Adjustments 1** and **Adjustments 2**). The implementation procedure of the first two steps have been nevertheless presented and discussed in this thesis.

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Adjustments 1 (ASHRAE)

1.1 ASHRAE Standards

a "subjective approach" to Internal Gains from People and Electric Equipment

- Activitiy schedules and occupancies determined following interviews with the building users
- Activity related heat gains extracted from ASHRAE Handbook of Fundamentals (Representative rates for activity levels including "being Seated"; "Standing"; "Sleeping"; "Cooking"; "House cleaning";)

1.2 Infiltration (ACH=0,4)

Standardized values extracted from the energy certificates

Adjustments 2 (ASHRAE + ÖNORM)

2.1 Austrian Standards

Parallel simulation with new schedules for internal gains taken from the ÖNORM B-8110-3:2020

- B-8110-3 Table 2 *People Heat gains*
- B-8110-3 Table 3 *Equipment Heat gains*
- when compared to the ASHRAE data, the ÖNORMs generally illustrate heat gains per m.-2 of floor area

2.2 Natural Ventilation

in addition to the infiltration, this trial is intended to include the natural ventilation occuring through the opening of windows

- Setpoint of natural ventilation assumed at 20 deg.C (i.e. the opening of windows is operated)
- Values extracted from the ÖNORM B-8110-3:2020 Table 4 *Specific Hygienic Air Flow in naturally ventilated spaces*
- implemented into E+ using the *ZoneVentilation:DesignFlowRate* Parameter

2.3 Heating Setpoint

This parameter was changed based on the presumption that due to user behavior the Average temperatures cannot be standardized. These values were later benchmarked in **Adjustments 3**

- Additional simulations undergone for Heating Set-Point Temperatures at 18, 19 & 21 deg.C.

Adjustments 3 (ÖNORM)

3.1 Simulation Benchmark

To quantify the role of the occupants in the buildings' EPG, the following bulleted parameters have been Benchmarked. These processes contribute to the identification of the EPG

- Heat gains and occupany according to ÖNORM B-8110-3:2020
- Benchmarking the DHW consumption of the dwellers
- Heating setpoint set as 20 deg.C

3.2 Normalization (Weather)

Weather data has been provided by the BST Department of the Vienna University of Technology for Y.2017 and Y.2018

3.3 Air Change per Hour (ACH) Calibration

The air change consistency occuring during one hour has been simulated for the "normalized" results.

The ACH=0,4 is benchmarked, ergo the (2.2) Natural Ventilation Parameter from Adjustment 2 is omitted.

Additional simulations undergone for:

- 0,6 ACH
- 0,8 ACH

Figure 14 Adjustments 1+2+3 and the steps taken in their implementation

2.8.1 Adjustments 1 and Adjustments 2

The first adjustment has been created using the heat gains extracted from the ASHRAE Book of fundamentals and occupancy schedules constructed in Energy Plus through the interpretation of interviews with the tenants.

In Adjustments 2, the energy demand has been simulated alongside the initial input data using new schedules and internal gains according to the ÖNORM B 8110-3:2020. In addition to the path used in Adjustment 1, simulations have been made for:

- Natural ventilation occurring through window operation. These values have been taken from Table 4 of the ÖNORM B 8110-3:2020
- Heating setpoint calibrated to 18, 19, and 21 deg.C.

Table 10 Adjustments 1 + 2: Calibration steps

Step	Adjustment	Calibration	Description
1.	Adjustment 1	Activity & occupancy schedules (acc. to tenant interviews)	Activity schedules and occupancies determined following interviews with the building users
2.	Adjustment 2	New Schedules - Internal Gains (acc. to the ÖNORM B8110)	The Activity Schedules have been adapted to the values in B-8110-3:2020 and ASHRAE Table 2 - People Heat Gains; Table 3 - Equipment Heat Gains
3.		Natural Ventilation Simulated (Setpoint = 20°C)	ZoneVentilation:DesignFlowRate added to the E+ Simulation; Values from B-8110-3:2020 Table 4 Specific Hygienic Air Flow in naturally ventilates spaces
4.		Heating Setpoint 18 °C	18 °C
5.		Heating Setpoint 19 °C	19 °C
6.		Heating Setpoint 21 °C	21 °C

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2.8.2 Adjustments 3

An analysis of the results of the first two adjustments has established the need of benchmarking certain indicators in the performed simulations. In a certain way, this step standardizes the behavior of the occupants using a deterministic approach to the factors that could clutter the identification of the EPG.

Table 11 Adjustments 3: Benchmarked factors (further calibration steps)

Step	Factor	Benchmark (resolution)	Reason
1.	Heat gains and occupancy	Adoption of ÖNORM B 8110-3:2020 values: *Table 2 Specific heat gain from equipment* *Table 3 Specific heat gains from people*	- More objective approach vs. evidence from tenant interviewing
2.	Weather "correction"	Normalization of results: Simulations carried out with the **weather data** obtained from the BST Faculty for **Y.2017** and **Y.2018** Weather files including outdoor temperatures, relative humidity, hours of daily sunshine, solar radiation, wind speed and wind direction	- used to isolate the contribution of occupant-related factors to EPG - enables a proper comparison of predicted and actual energy geometry, construction and occupancy patterns when comparing before-after energy use
3.	Heating Setpoint	Set to 20 deg.C	- indoor temperatures have not been monitored

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The climate data files for the normalization of weather have been provided from the weather station at the Building Science and Technology Department of the TUWien.

Figure 15 A map representation of the distance from the TUWien weather station to the Am Freihof 33 building (app. 9 km)

A value that has not been benchmarked, yet it displays a considerable effect on the space heating demand is the **air change per hour rate (ACH)**. Air change in a space occurs because of window operation and the infiltration occurring though the building envelope. The Austrian Standard ÖNORM B 8110-5:2019 stipulates an air change rate (ACH) of 0.4 h^{-1} for the calculations of energy certificates. Housez presents in his doctoral thesis (Housez et al. 2014), that much larger air rates are to be entered into calculations in order to provide closer estimates of actual heating demand, claiming that model assumptions for air change rate needed to be higher by a factor of 4-6 than the energy certificates in the buildings that were analyzed in the mentioned work. With the intention of observing how much can the change in ACH affect the real space heating demand, further simulations have been done with **0.6 h^{-1}** and **0.8 h^{-1} ACH**.

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3 RESULTS AND DISCUSSION

3.1 Energy bills data

Collecting information about the consumption data in buildings is a challenging process, which solely depends on the people's responsiveness and interest. Certain approaches had to be put into play when convincing the dwellers to participate in this thesis. Initially, the intention was to bypass the interviews, however due to data privacy reasons, companies like WienEnergie and Wiener Netze are not too committed to contribute with consumption information. Because of a lack of public database, and the bureaucracy involved in requesting the information through the energy providing companies, it was decided to meet up in person with each building tenant and request all their heating energy bills. This chapter includes figures to help illustrate the collected data.

By compiling the collected meter information, we can observe that there is a general trend of energy consumption reduction following the renovation. On average the gas consumption has been decreased by 32%, a number that includes both space heating and DHW consumption.

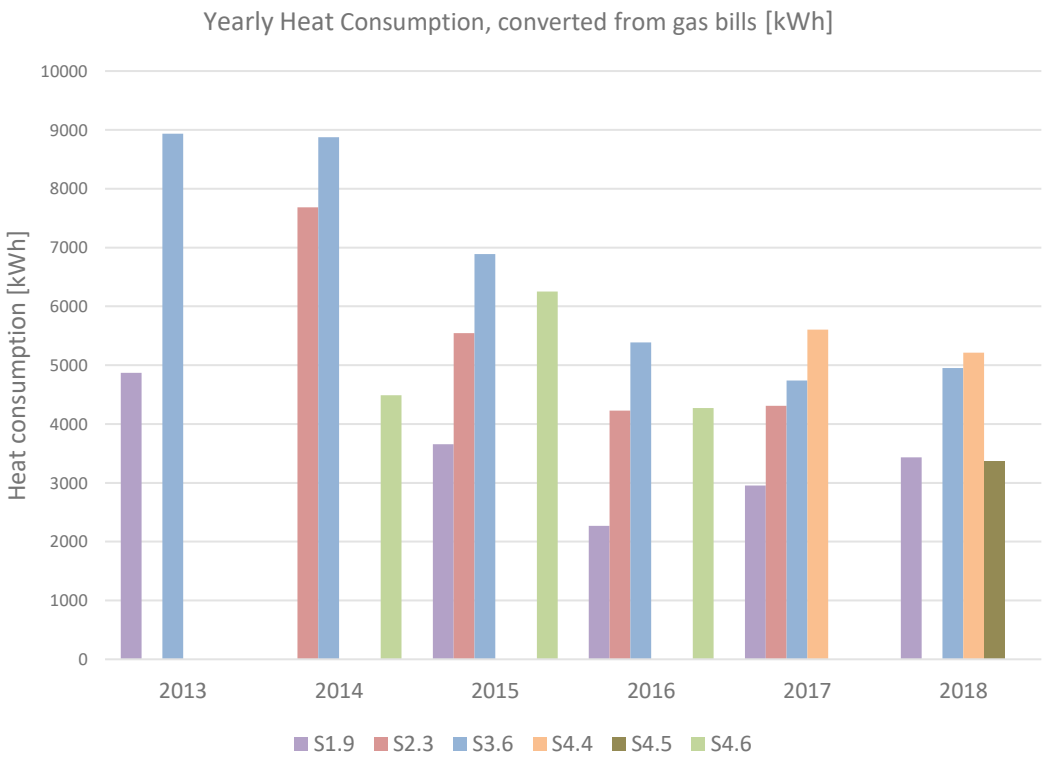

Figure 16 Energy bills data from year 2013 to 2019

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At this phase of the assessment, the energy bills data is not proportionately visualized throughout the period between Y.2013 – Y.2019 due to missing information from the side of the users. Because of this, the values for energy consumption have been averaged for before the retrofit and after the retrofit in order to generate more representative graphs.

Table 12 Representation of the reduction of heating consumption following the refurbishment

Apartment	Net Floor Area [m²]	Average Energy Demand [kWh.m^{-2}]		Reduction of heat consumption [%]
		Pre-retrofit	Post-retrofit	
S1.9	27.96	153	103	32
S2.3	54.63	121	78	35
S3.6	64.68	127	78	39
S4.4	54.38	-	99	-
S4.5	28.17	-	119	-
S4.6	54.38	99	79	20

Practically speaking, a planning company will most often guarantee contractually a certain amount of energy reduction (keeping in mind the intention of sinking costs and limiting liability). Previously it was observed that the architects have estimated a reduction of about 80% in the energy certificate – a value which is unlikely to be reached. A reduction of 32% deems to satisfy the end user, which is the case in the Am Freihof 33, where the interviewed people have observed a general improvement of their well-being and also a reduction in their energy costs.

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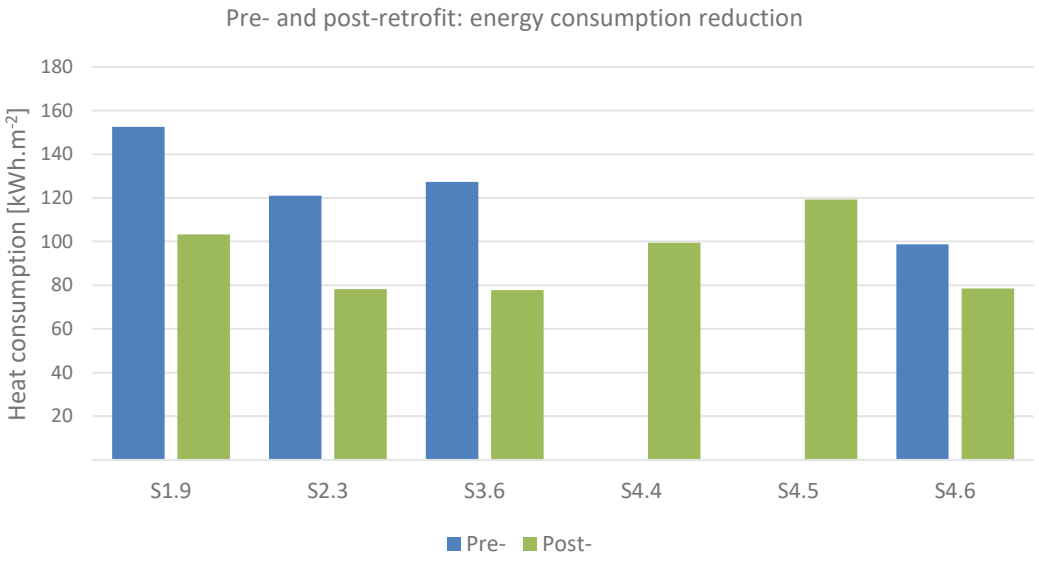

Figure 17 Energy consumption before and after renovation (average values; represented according to the energy bills)

Missing pre-retrofit energy bills data for the apartments S4.4 and S4.5 is due to the change in tenants occupying these spaces. Also, the deviation in heat demand for S1.9 and S4.5 when compared to the rest of apartments is explained by the reduced floor area and external building envelope exposure, these spaces being located on the upper floor at the gables of the building (see apartment location: Figure 10 Illustration generated through SketchUp – representation of the apartments' location).

A more exhaustive visualization of the heating demand could be produced for the apartment S.3.6, thanks to a more extensive energy bill dossier collected for the period between Y.2005 to Y.2019 by Ms. Jeschoffnig (the inhabitant of S.3.6). During the interviewing process it was deduced that the above-mentioned dweller is aware of her carbon-print and tries to be as energy efficient as possible. Further investigations have revealed this subject to be an outlier among the participants.

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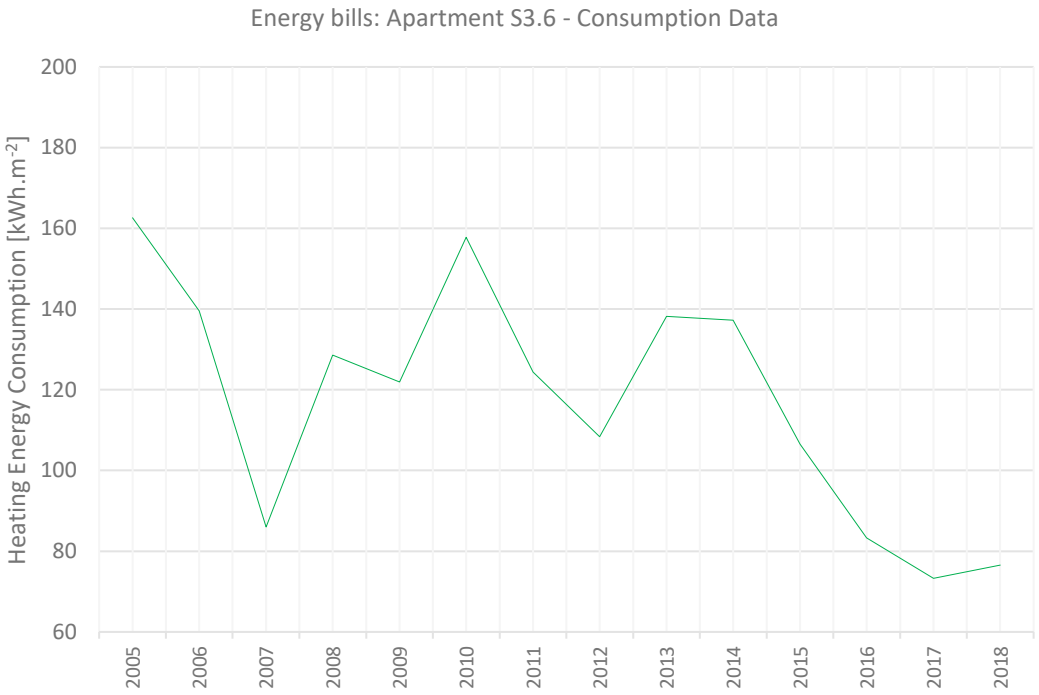

Figure 18 Apartment S3.6: heat energy consumption from 2005 to 2019 (energy bills)

The anomaly noticed between 2007 and 2008 is argued by the fact that the tenant of this apartment has not been dwelling in it for most of this period. A clear reduction is to be noticed following the refurbishment in Y2015 – Y.2016.

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3.2 Domestic hot water component

As presented in the evaluation method (see 2.5), it was necessary to estimate a realistic number for the Domestic Hot Water (DHW) consumption as a benchmark, with the scope of extracting the said value from the energy bills, to calculate the space heating demand.

Table 14 represents the calculated DHW consumption according to three different approaches, the first two presented by Fuentes (Fuentes et al. 2018): (1) the EN Method, according to the consumption profiles represented in the European Norm EN16147:2011; (2) the Annex 42 Method, values taken from the International Energy Agency Report; and (3) the B8110-5 or the values provided by the ArchiPhysik Energy Certification Program.

Table 13 DHW consumption estimation according to (1) EN; (2) Annex 42; (3) ÖNORM

		Approach 1 (*EN*)					**Approach2 *Annex 42***	**Approach 3 *B8110-5***
	Net Floor Area [m²]	**S (EN)**	**M (EN)**	**L (EN)**	**XL (EN)**	**XXL (EN)**		
Daily load acc. to EN16147:2011 [kWh/day]		*2.1*	*5.85*	*11.66*	*19.07*	*24.53*	-	-
Daily DHW consumption (Germany) Annex 42		-	-	-	-	-	*8.36*	-
S1.9	27.96	27	76	152	249	320	44	8
S2.3	54.63	14	39	78	127	164	22	8
S3.6	64.68	12	33	66	108	138	19	8
S4.4	54.38	14	39	78	128	165	90	8
S4.5	28.17	27	76	151	247	318	130	8
S4.6	54.38	14	39	78	128	165	90	8

Table 15 shows the results of the different approaches used in benchmarking the DHW consumption; a graphical representation is presented in Figure 19.

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Table 14 Estimation of DHW consumption according to the European Norm EN16147:2011 (1); Annex 42 Method, values taken from the International Energy Agency Report (2), and the Austrian Standard B8110-5 (3)

#	Net Floor Area [m²]			S (EN) (1)	M (EN) (1)	L (EN) (1)	XL (EN) (1)	XXL (EN) (1)	Annex 42 (2)	B8110-5 (3)
S1.9	27.96	DHW	$kWh.m^{-2}$	27.4	76.4	152.	248.9	320.2	43.7	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	103.2	103.2	103.2	103.2	103.2	103.2	103.2
		DHW Ratio (Post-)	%	27	74	147	241	310	42	7
		HD_{Total} (Pre-)	$kWh.m^{-2}$	174.2	174.2	174.2	174.2	174.2	174.2	174.2
		DHW Ratio (Pre-)	%	16	44	87	143	184	25	4
S2.3	54.63	DHW	$kWh.m^{-2}$	14.0	39.1	77.9	127.4	163.9	22.3	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	78.2	78.2	78.2	78.2	78.2	78.2	78.2
		DHW Ratio (Post-)	%	18	50	100	163	210	29	10
		HD_{Total} (Pre-)	$kWh.m^{-2}$	121.1	121.1	121.1	121.1	121.1	121.1	121.1
		DHW Ratio (Pre-)	%	12	32	64	105	135	18	6
S3.6	64.68	DHW	$kWh.m^{-2}$	11.9	33.0	65.8	107.6	138.4	18.9	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	77.7	77.7	77.7	77.7	77.7	77.7	77.7
		DHW Ratio (Post-)	%	15	42	85	138	178	24	10
		HD_{Total} (Pre-)	$kWh.m^{-2}$	127.3	127.3	127.3	127.3	127.3	127.3	127.3
		DHW Ratio (Pre-)	%	9	26	52	85	109	15	6
S4.4	54.38	DHW	$kWh.m^{-2}$	14.1	39.3	78.3	128.0	164.6	89.8	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	99.5	99.5	99.5	99.5	99.5	99.5	99.5
		DHW Ratio (Post-)	%	14	39	79	129	166	90	8
S4.5	28.17	DHW	$kWh.m^{-2}$	27.4	75.8	151.1	247.1	317.8	130.0	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	119.3	119.3	119.3	119.3	119.3	119.3	119.3
		DHW Ratio (Post-)	%	23	64	127	207	266	109	6
S4.6	54.38	DHW	$kWh.m^{-2}$	14.1	39.3	78.3	128.0	164.6	89.8	7.7
		HD_{Total} (Post-)	$kWh.m^{-2}$	78.6	78.6	78.6	78.6	78.6	78.6	78.6
		DHW Ratio (Post-)	%	18	50	100	163	210	114	10
		HD_{Total} (Pre-)	$kWh.m^{-2}$	98.8	98.8	98.8	98.8	98.8	98.8	98.8
		DHW Ratio (Pre-)	%	14	40	79	130	167	91	8

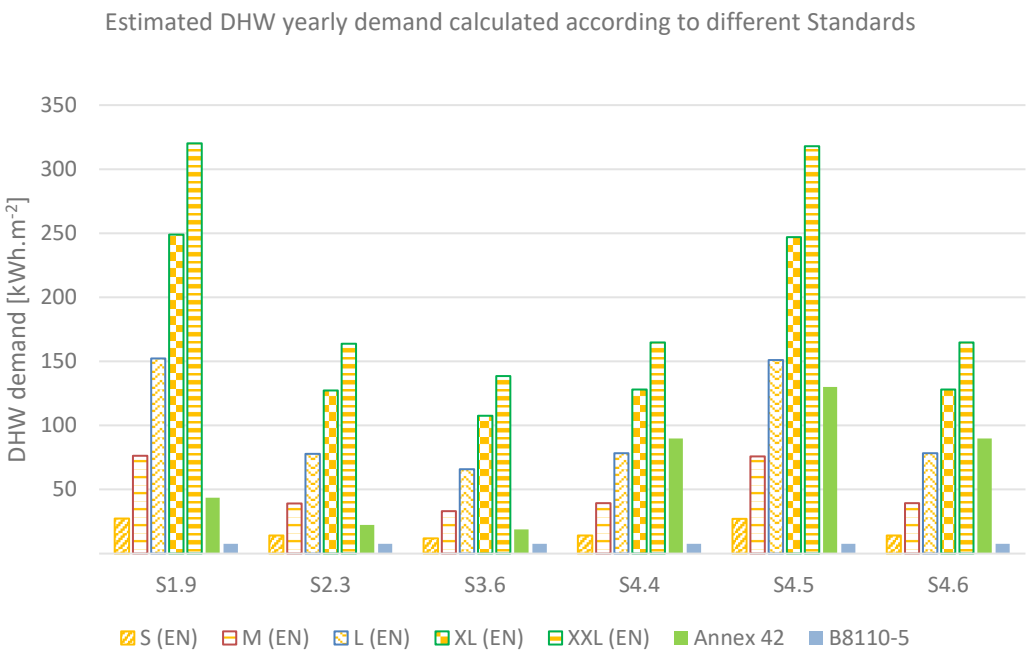

Figure 19 Graph: DHW Consumption calculated for each apartment according to the 3 Approaches

The elaboration of the following graph (DHW consumption for apartment S1.9) has contributed to benchmarking the DHW values for the assessed apartments. It was made with the purpose of identifying the DHW component of the total heating consumption, where the user profile S of the European Norm has indicated a more realistic ratio of DHW to space heating consumption (with a 16% of the total heating demand before retrofit, and 26% after retrofit).

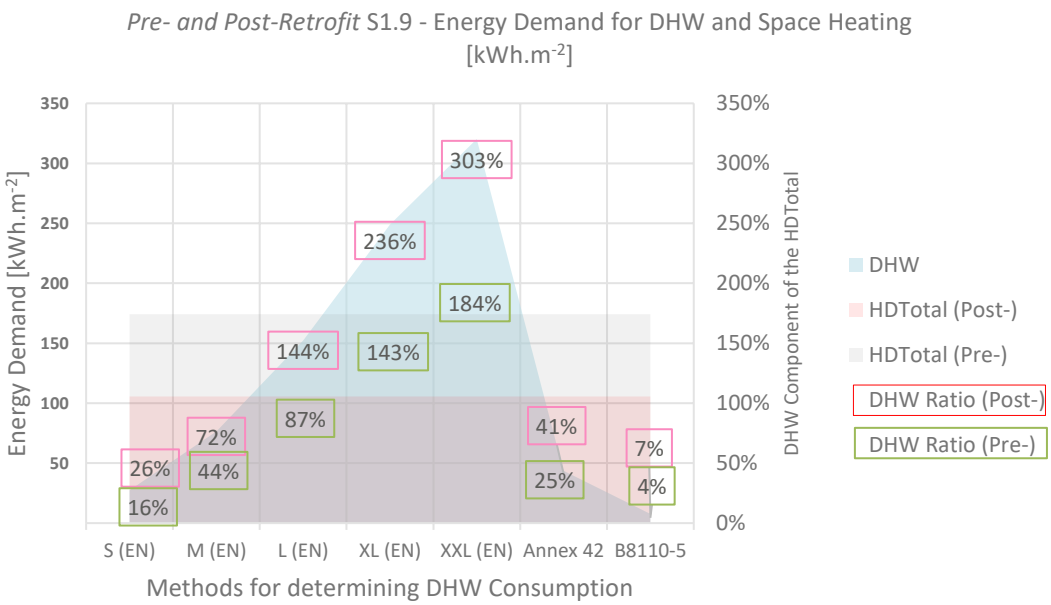

Figure 20 DHW vs Space heating consumption for the pre- and post-retrofit scenarios (S1.9)

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The blue mountain-shaped figure represents the results of the various approaches made in Table 14 Estimation of DHW consumption, where the stacked areas are the heating consumption before (grey) and after (pink) renovation. Finally, the benchmarked values for the DHW consumption are shown in Figure 21.

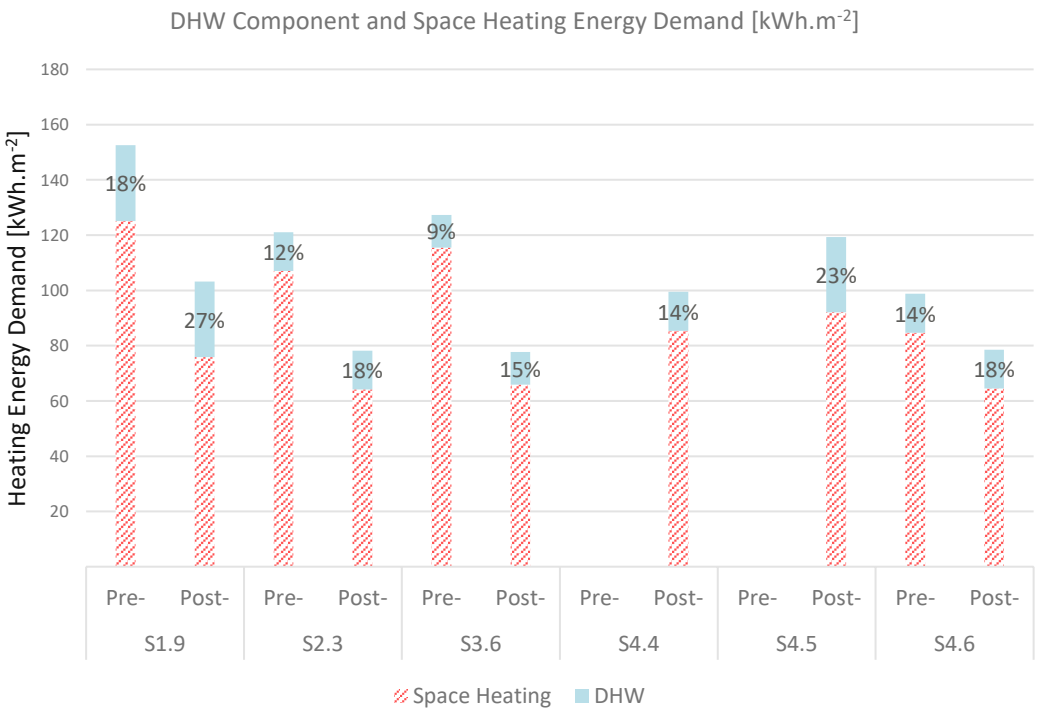

Figure 21 Benchmarked DHW consumption

Subsequently, the values used to contrast the resulting simulation results do not include the DHW demand. These are presented in the previous Figure 21 in percentage [%] amount from the energy bills. DHW demand ranges among the apartments between 9% to 18% pre-retrofit and between 14% and 27% post-retrofit.

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3.3 Adjustments 1 and Adjustments 2

This chapter informs the reader about the results of the Adjustments 1 and 2 generated through building simulation. The proposed structure for the following 6 pages (1 page per apartment) includes:

1. a table for each assessed dwelling with the surface area and occupancy information, followed by
2. the graphical illustration of the results for each carried out calibration (see details Table 10 Adjustments 1 + 2: Calibration steps) for the (2) pre-retrofit conditions and then the (3) post-retrofit conditions. For comparison, the graphs also include a linear representation of the energy certificate results and the space heating energy consumption (energy bills).

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Table 15 S1.9 occupancy and area information

Apartment	Net Floor Area [m²]	Occupancy [Persons]
S1.9	27.96	1

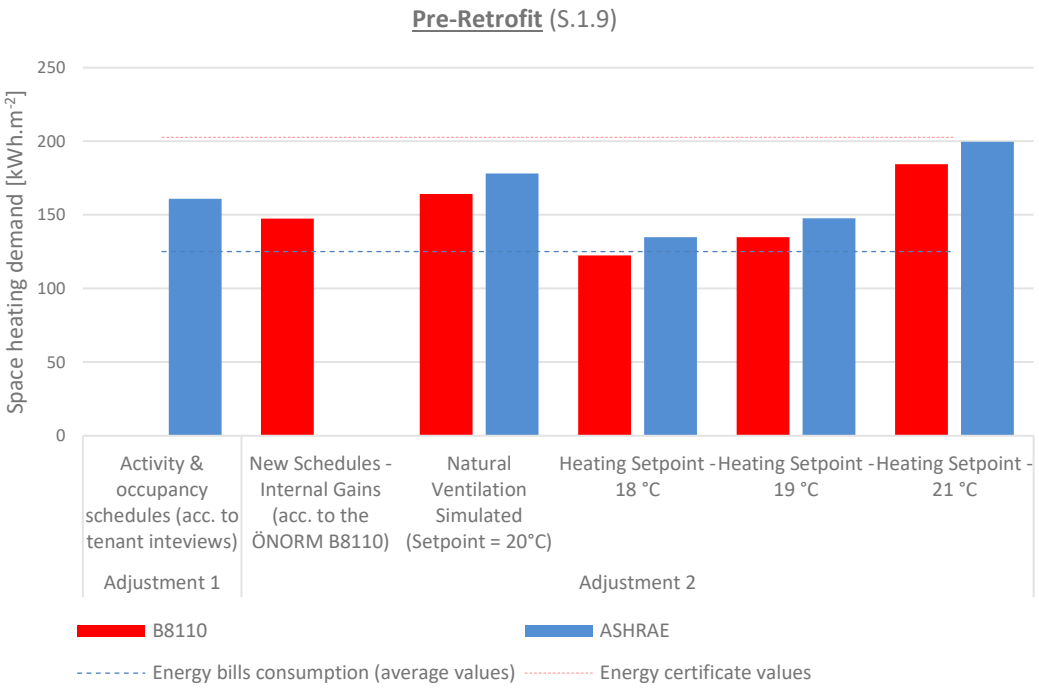

Figure 22 S1.9: pre-retrofit results of Adjustments 1 + Adjustments 2

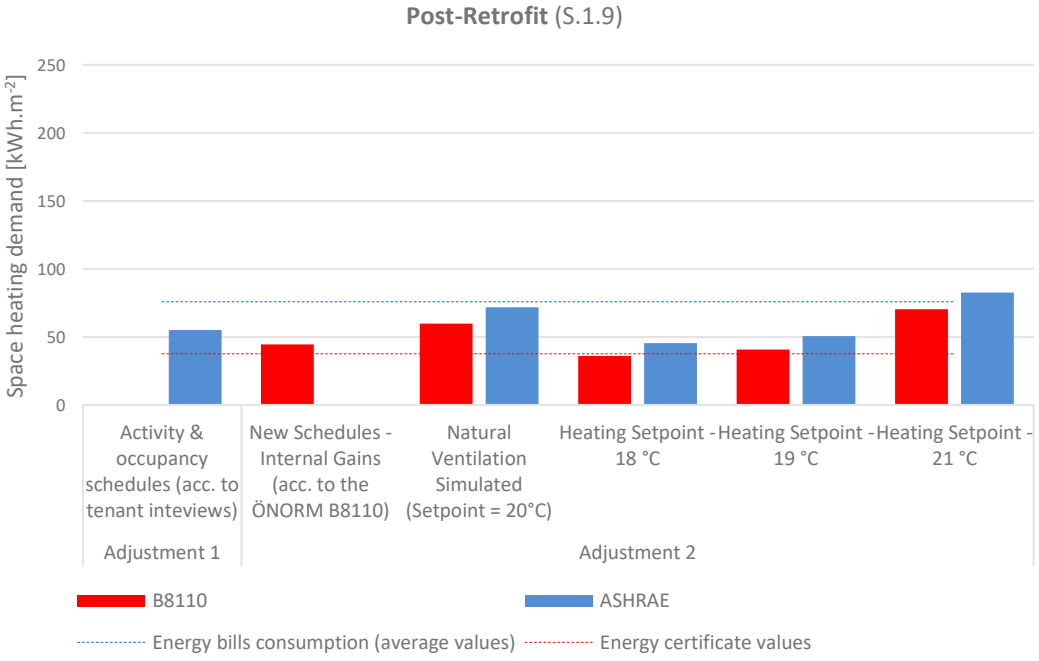

Figure 23 S1.9: post-retrofit results of Adjustments 1 + Adjustments 2

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Table 16 S2.3 occupancy and area information

Apartment	Net Floor Area [m²]	Occupancy [Persons]
S2.3	54.63	1 Person

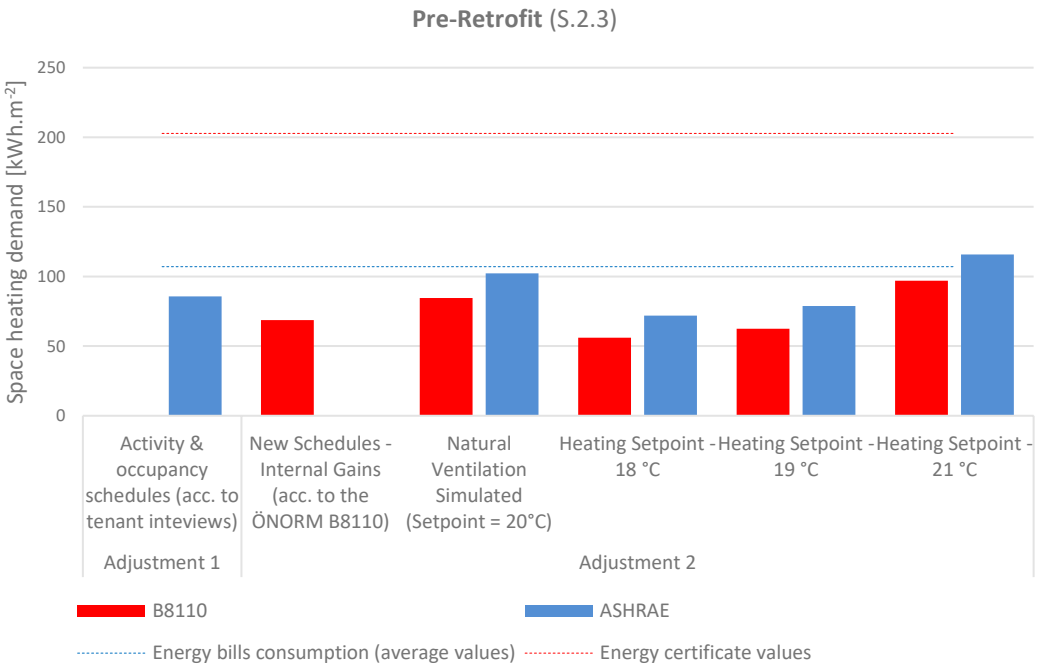

Figure 24 S2.3: pre-retrofit results of Adjustments 1 + Adjustments 2

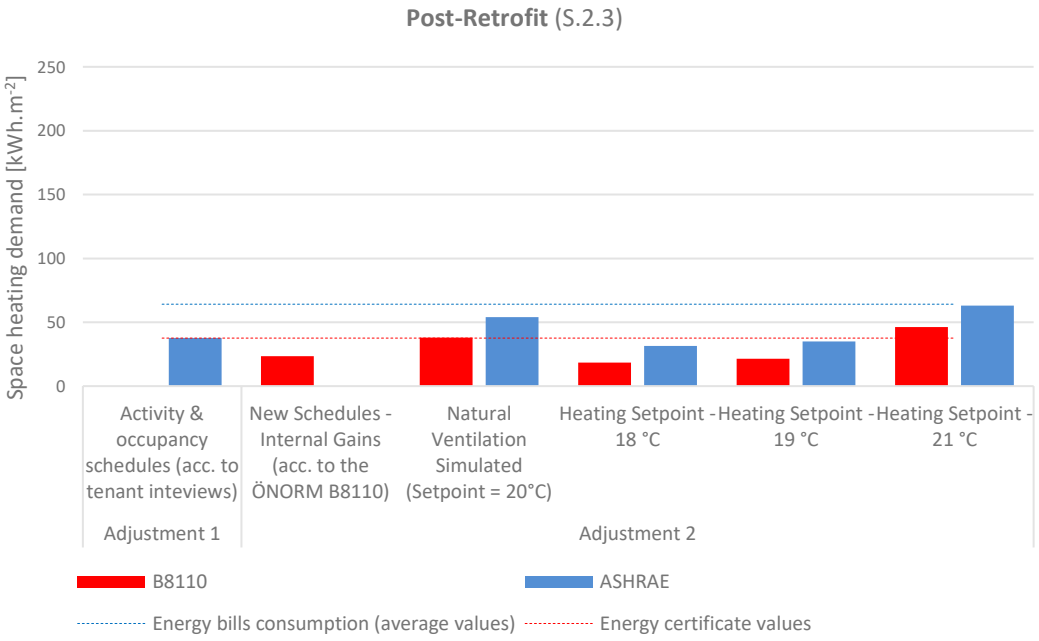

Figure 25 S2.3: post-retrofit results of Adjustments 1 + Adjustments 2

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Table 17 S3.6 occupancy and area information

Apartment	Net Floor Area [m²]	Occupancy [Persons]
S3.6	64.68	1

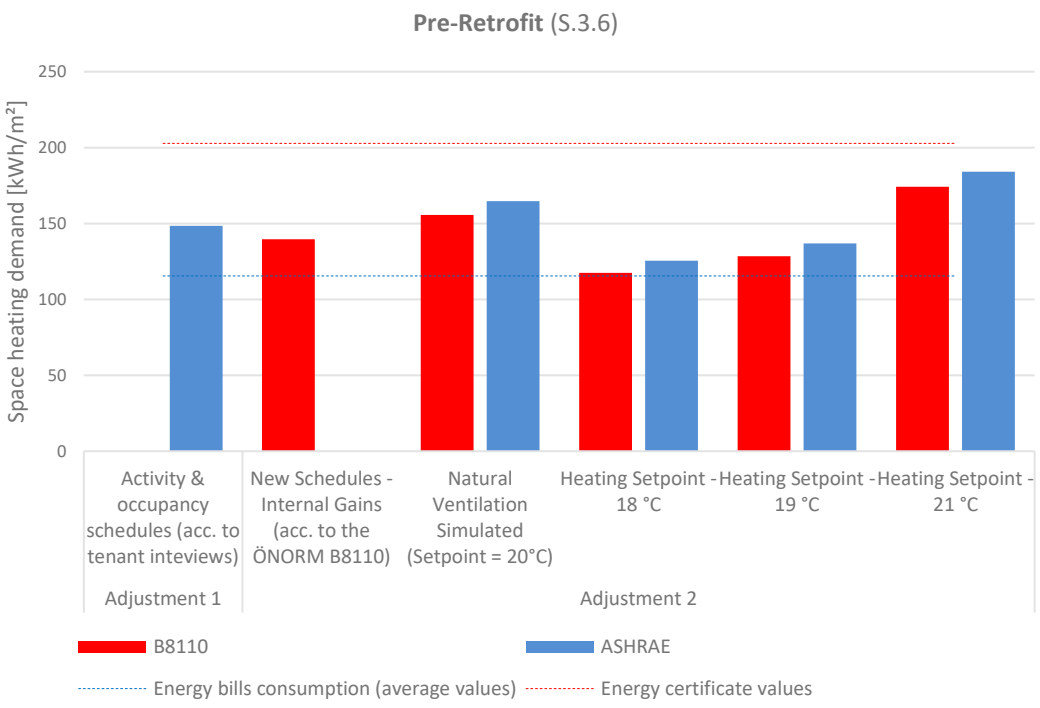

Figure 26 S3.6: pre-retrofit results of Adjustments 1 + Adjustments 2

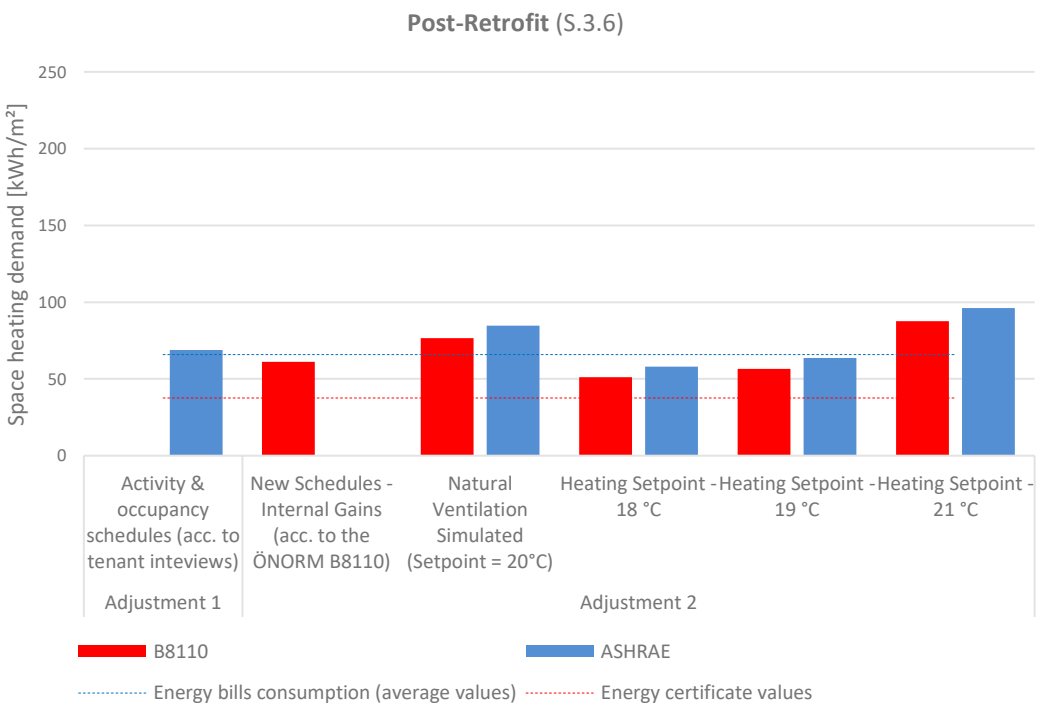

Figure 27 S3.6: post-retrofit results of Adjustments 1 + Adjustments 2

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Table 18 S4.4 occupancy and area information

Apartment	Net Floor Area [m²]	Occupancy [Persons]
S4.4	54.38	4

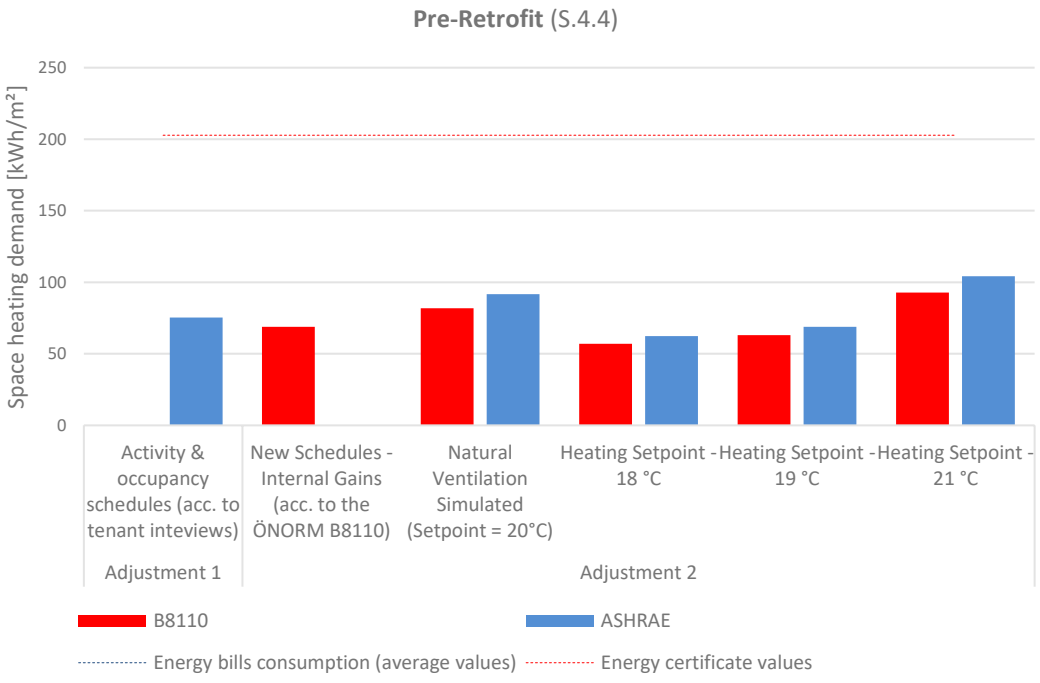

Figure 28 S4.4: pre-retrofit results of Adjustments 1 + Adjustments 2

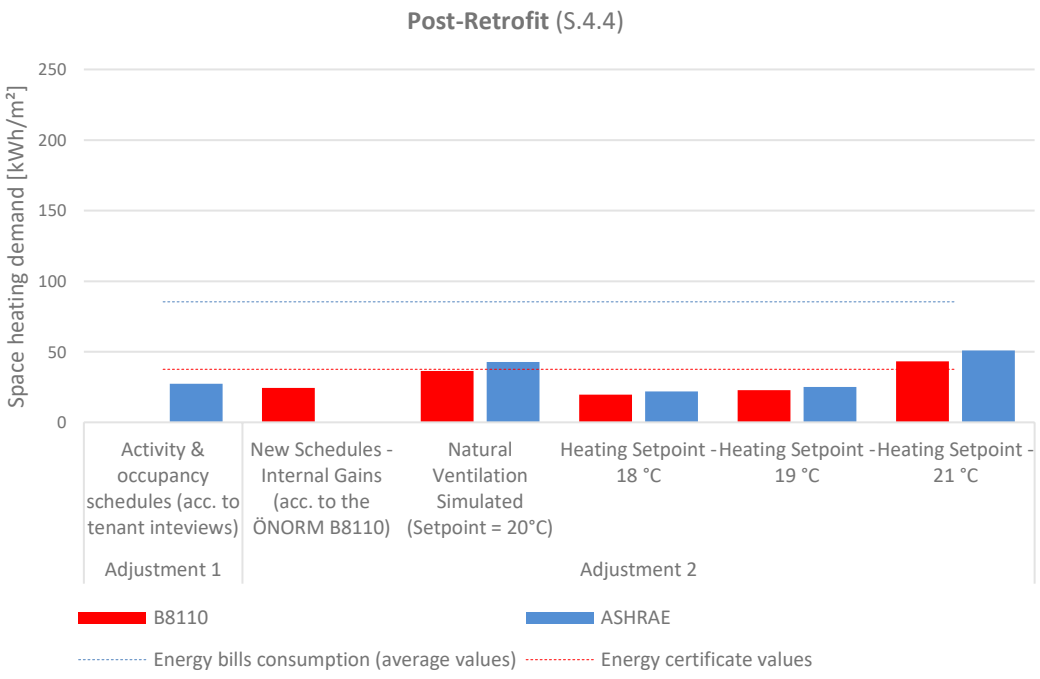

Figure 29 S4.4: post-retrofit results of Adjustments 1 + Adjustments 2

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Table 19 S4.5 occupancy and area information

Apartment	Net Floor Area [m²]	Occupancy [Persons]
S4.5	28.17	3

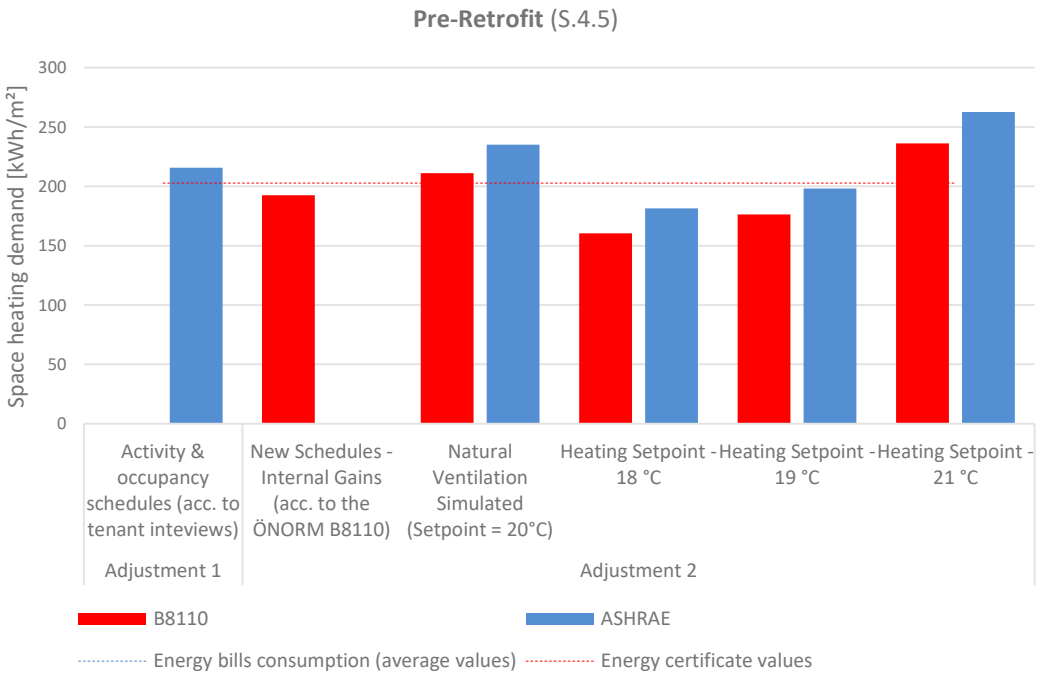

Figure 30 S4.5: pre-retrofit results of Adjustments 1 + Adjustments 2

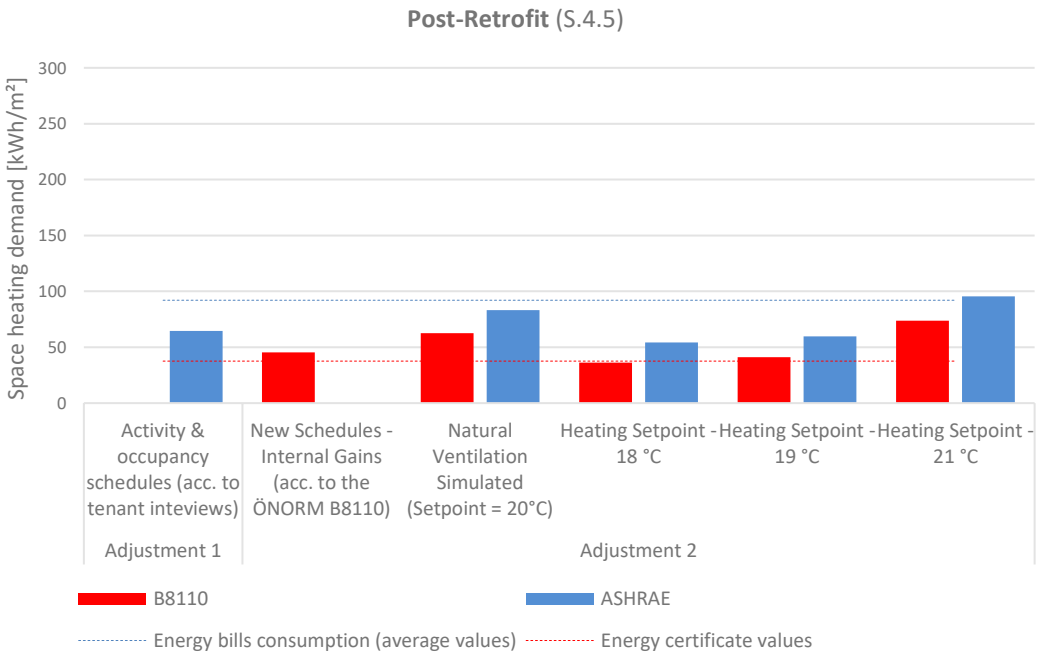

Figure 31 S4.5: post-retrofit results of Adjustments 1 + Adjustments 2

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Table 20 S4.6 occupancy and area information

Apartment	Surface area [m²]	Occupancy [Persons]
S4.6	54.38	4

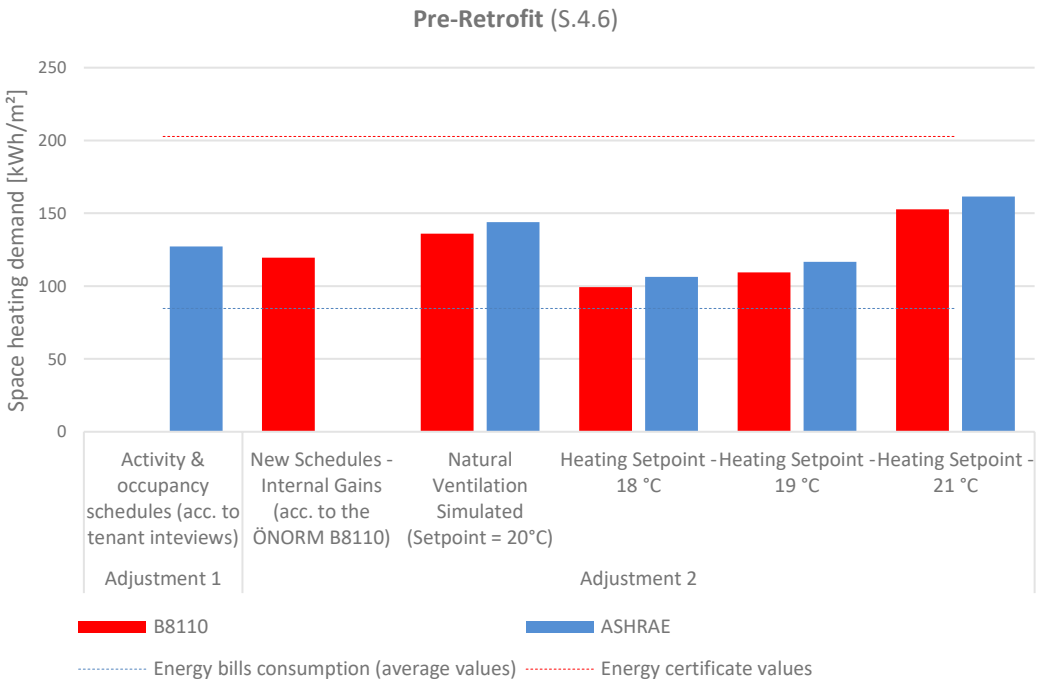

Figure 32 S4.6: pre-retrofit results of Adjustments 1 + Adjustments 2

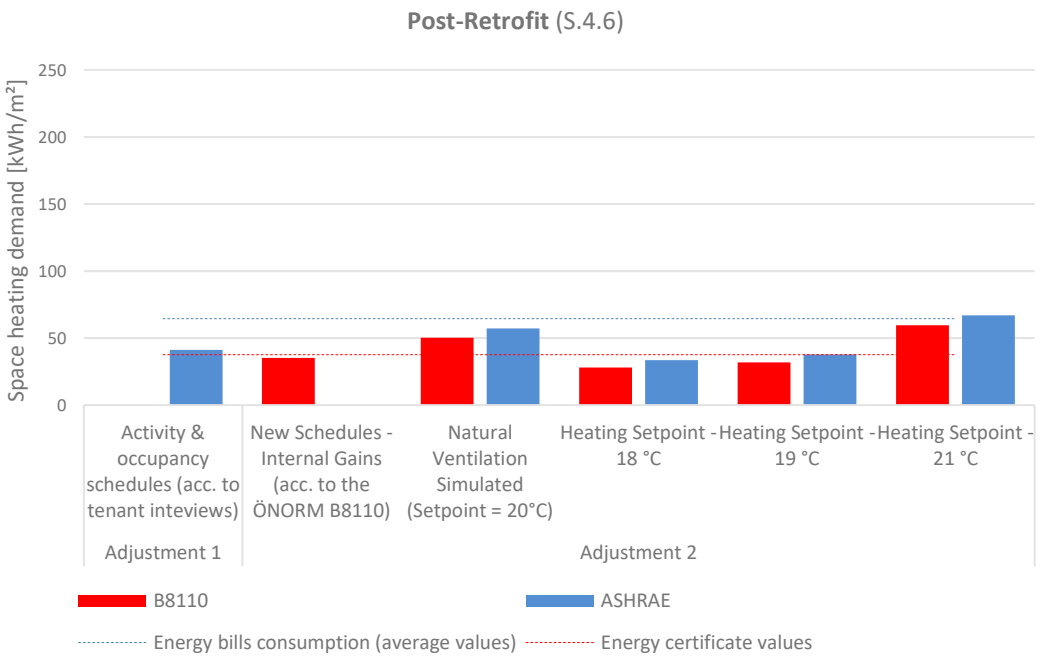

Figure 33 S4.6: post-retrofit results of Adjustments 1 + Adjustments 2

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It can be observed that the occupancy and internal heat gains from ASHRAE indicate a larger demand for space heating than the ones generated through the ÖNORM values. A more accurate depiction would require monitoring the indoor climate before and after renovation. The heating energy demand seems to grow in a linear manner after each 1 K increase in heating setpoint, however a more considerable increase is observed between the 20 and 21 degrees Celsius of heating setpoint. It is in fact a consequence of the addition of natural ventilation, where the simulation program applies it as soon as the outdoor temperature reaches 20 degrees Celsius. Higher fluctuations usually occur in transitional seasons such as Autumn and Spring which in turn may argue the attempt of the simulation to prompt a heating demand due to increasing air changes at bordering heating setpoints.

The apartment S4.4 and S4.5 graphs for the period before renovation do not include a linear representation of the average heating consumption, explained by the fact that the current tenants have moved in right after Y.2016, meaning that there is no access to the previous consumption data.

A peculiar trend noticed in the graphs above is that the energy certificate and the average energy bills data lines interchange after renovation. Energy labelling is always performed on the entire building and does not focus on each apartment separately, regardless the energy certificates seem to provide a higher heating demand than the real consumption before-, and a lower one compared to the energy bills, after-renovation. Real consumption data represent from 42% up to 62% of the energy certificate values before renovation, on the other hand, it stands between 71% and 145% higher than the energy certificate after renovation. This fact can either suggests that energy certificates may overestimate the demand of non-renovated buildings, or that a rebound effect is present in this case study. This suspicion would require additional analysis of the indoor climate conditions prior to the retrofit. At this step it is premature to determine the reason for Energy Performance Gap.

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3.4 Adjustments 3

The necessity for a more accurate calibration of the initial two adjustments is argued by the divergence of the made assumptions. For example: different standards (ASHRAE and ÖNORM) have been used at times simultaneously, or that the window operation and therefore occurrence of natural ventilation in the building simulation has been implemented. Even though previous results demonstrate how the implementation of certain factors affect the final space heating demand, it may seem like the chosen approaches attempt (and succeed) to reach the real energy bills data. The *Adjustments 3* has been devised to prevent uncertainties by offering a deterministic approach through benchmarking user behavior (e.g., input schedules and internal gains according to the ÖNORM B8110-3:2020), weather data (Y.2017 and Y.2018)) and simulating the effect of ACH on the total demand. The focus is laid on identifying a probable EPG.

3.4.1 Benchmarking (user behavior)

As proposed in 2.8.2, the next simulations have been made by adopting the ÖNORM values for the internal heat gains and occupancy schedules. At this phase, we are still comparing the average values of the energy bills with the simulation results.

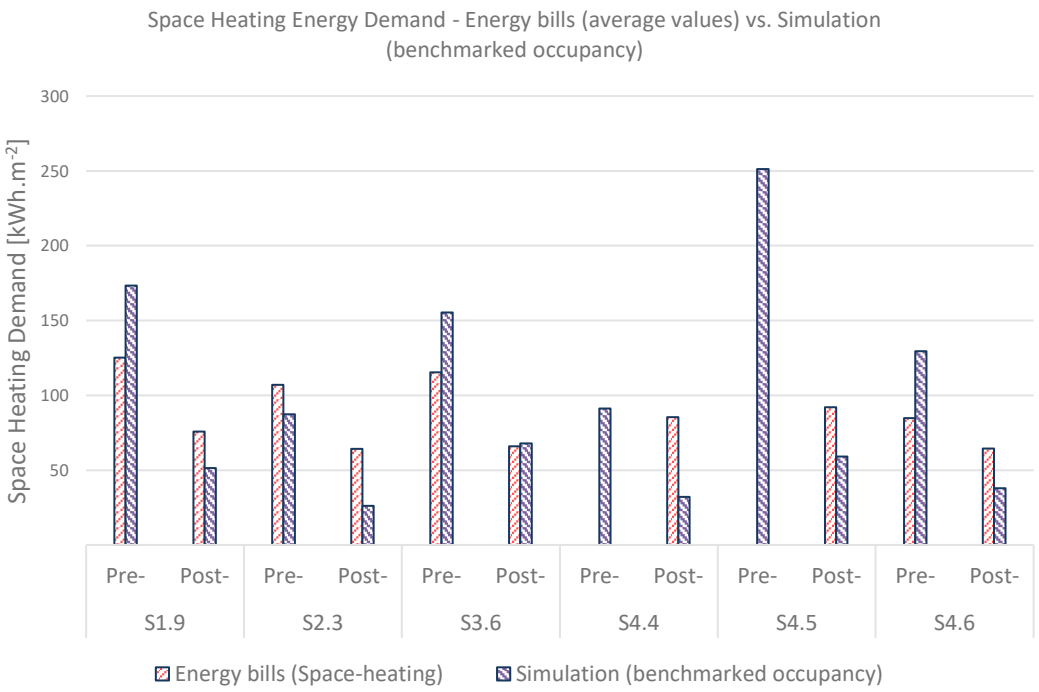

Figure 34 Adjustments 3: Energy bills data vs. Benchmarked user behaviour

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There is an obvious correlation between the energy bills and the benchmarked simulation. Except in the case of apartment S2.3, where the simulation benchmark results in a higher demand when compared to the actual demand. Compared to the rest of the apartments, S2.3 and S4.4 are located on the 3rd floor of the building, this way there is less external envelope surrounding these spaces, meaning less heat loss. Regardless, the tenant in S2.3 seems to be a spender or an above average consumer, which might be explained by the fact that he is a single tenant and thus wastes more energy to heat the space with less internal gains. The dwellers in S1.9 and S4.5 are (as expected) the highest spenders; with apartments located at the gables of the building, S4.5 surpasses S1.9 due to its north facing walls and windows.

3.4.2 Normalization (weather data)

Normalization refers to the "correction" of the weather conditions in the Energy Plus files, which facilitates a viable comparison between the simulated and actual energy consumption. The following simulations have been performed with weather files for 2017 and 2018, acquired from the weather station at the Building Science and Technology department at the Vienna University of Technology. Such an approach can help isolate the contribution of occupant related factors to EPG, which is done by assessing the differences in the results of the "standardized" user behaviour simulation against the energy bills.

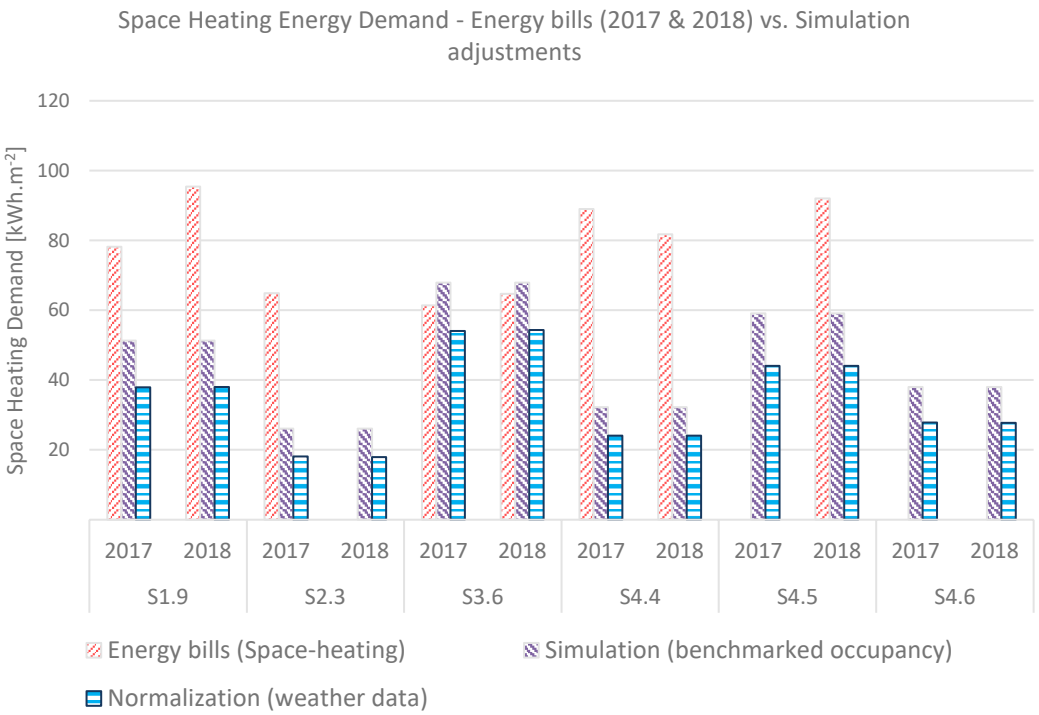

Figure 35 Adjustments 3: Simulation results after weather correction (normalization)

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In the figure above, the comparison between the real heating demand, previously standardized simulation and the normalized simulation indicates a potential for energy reduction, also a significative effect of the energy performance gap on the heat consumption.

Even though the building simulations portray almost the same heating energy demands for both Y.2017 and Y.2018, the energy bills show contradictory results. In some cases (e.g., S1.9; S3.6) the bills show increasing demands, whereas in others (S.4.4) decreasing heat consumption. This should be an effect of the user behavior and at the same time, however unlikely, due to possible deviations in the climate conditions at the building site and/or the BST Department Weather Station.

3.4.3 Energy Performance Gap

When calculating the Energy Performance Gap between the Energy Bills data after renovation against the "normalized" simulation results, the EPG [in%] distribution is around 51% on average – a value that does not deviate from the 55% among the studies in this domain (Mahdavi et al. 2021). All the simulations have resulted in a lower energy demand than the actual measured ones. The deviation can be arithmetically represented through the formula

$$Deviation = 1 - \frac{Simulation\ result\ (Weather\ Normalization)}{Measured\ Heat\ consumption\ (Energy\ bills)}$$

Table 21 EPG Rate [%] for the years 2017 and 2018

Simulation period [Year]	Apartment	EPG Rate [%]
2017	S1.9	52
	S2.3	72
	S3.6	12
	S4.4	73
	S4.5	-
	S4.6	-
2018	S1.9	60
	S2.3	-
	S3.6	16
	S4.4	71
	S4.5	52
	S4.6	-

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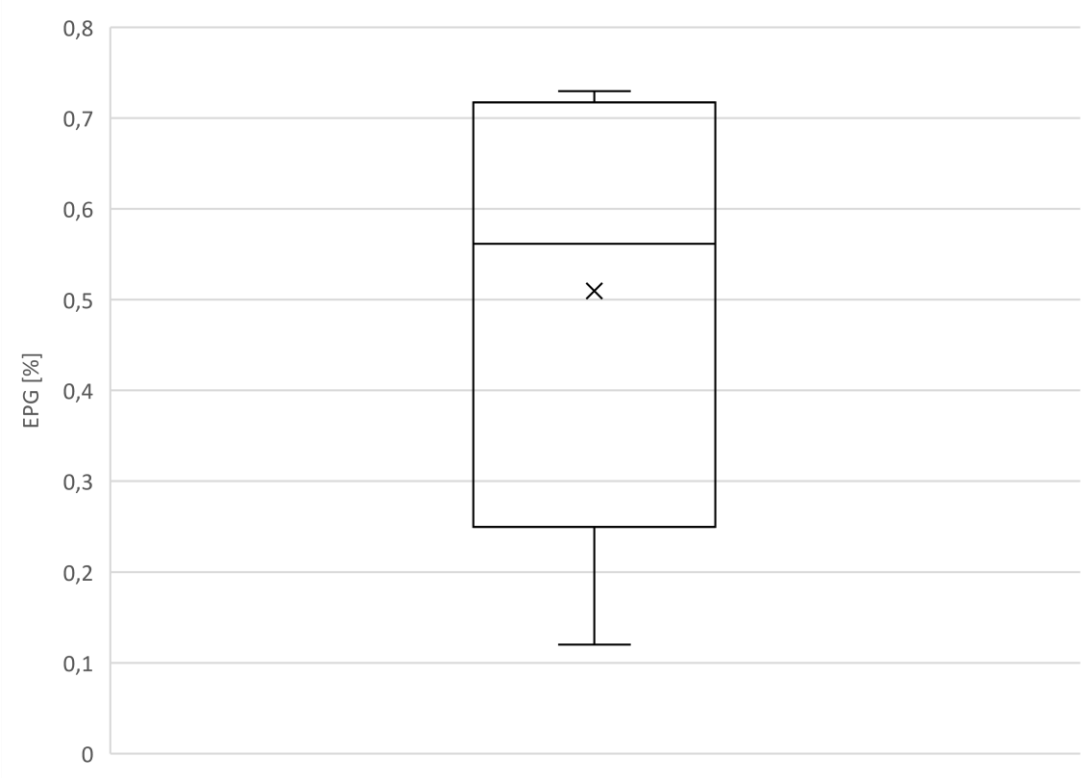

Figure 36 Graph: distribution of the EPG [%] in the analysed apartments for 2017 and 2018.

As hypothesized during the interpretation of the real consumption data and interviews, the tenant in S3.6 is an outlier amongst the analyzed dwellings (12% EPG), having presented themselves as a self-aware person with regards to their energy consumption and carbon-footing.

3.4.4 Adaptation of air change rates

The results of the simulations carried out with an ACH rate of 0,6 h^{-1}, and 0,8 h^{-1} have been delivered in the Figure 37 with the purpose of indicating the effect on the energy demand of a 50% and 100% ACH increase.

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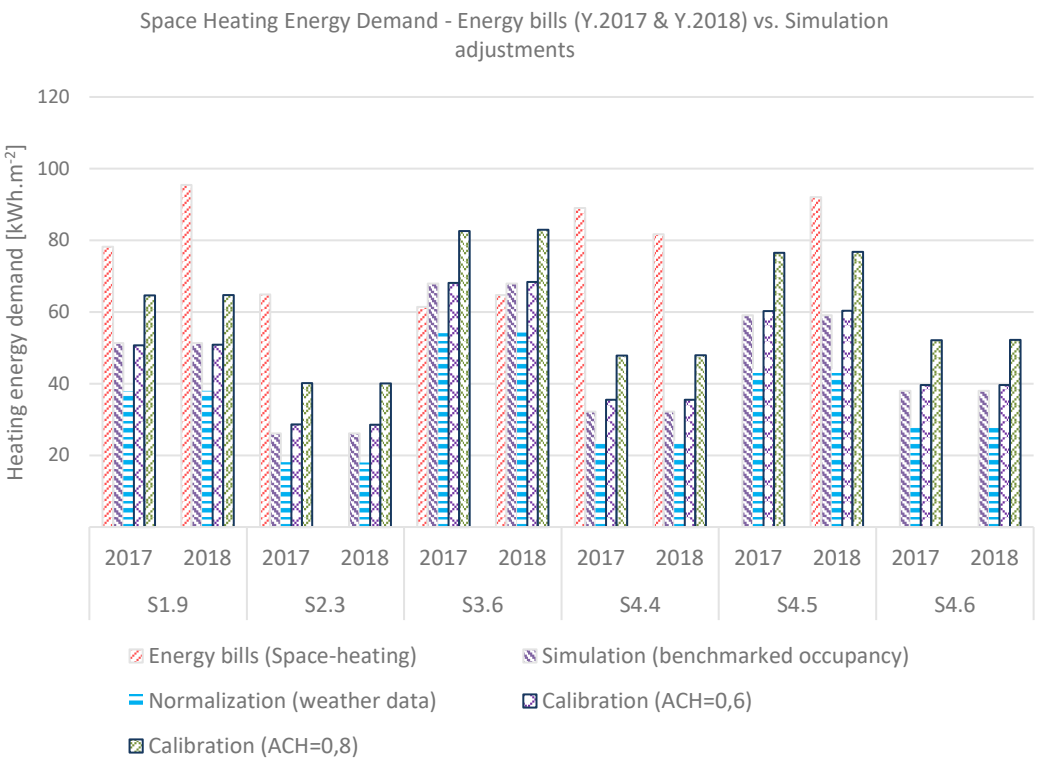

Figure 37 Adjustments 3: effect of the Air Change Calibration on the heating demand

The motivation behind simulating ACH contrary to the calibration of heating set-points is the argumentation brought by Housez (Housez et al. 2014) in his thesis, where he specifically observed that air change rates will account for the biggest influence on the building's energy performance. It was of interest to see how much the calibration of ACH affects the energy demand of the case study building.

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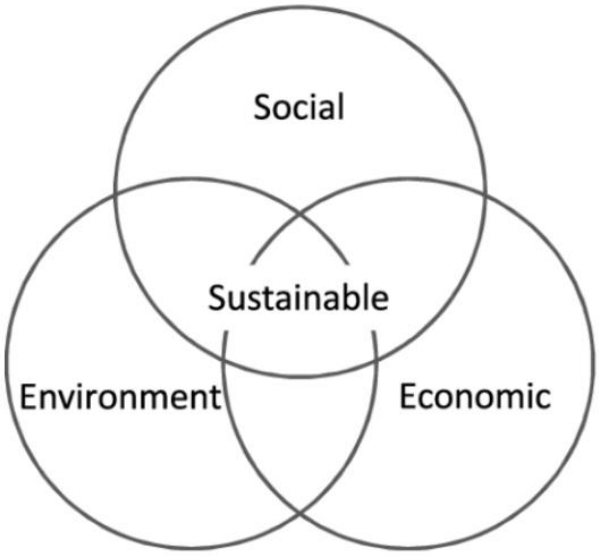
3.5 Return on investment (ROI)

Environmental protection and achieving a beneficial social impact are not the only tenets of improving the wellbeing. In fact, there are three main aspects to be considered when guaranteeing a high-quality life. These are also called the three pillars of sustainability: provision of social satisfaction, a thriving environment, and an acceptable degree of economic welfare.

Figure 38 Sustainability diagram – a conceptual representation of the main features for reaching sustainability



One of the essential questions asked during renovations is: how can we improve the well-being of the tenants in a financially feasible manner? The information provided through energy bills can be used in determining the payback period of the retrofit project, by calculating a simple Return of Investment (ROI). The established Energy Performance Gap can be further used in assessing the potential for ameliorating the ROI.

The renovation costs have been estimated at EUR 647,732.75, which accounts for EUR 480.18 per square meter (renovated area is 1348.94 m^2). According to the performed energy audit by Wohnfonds Wien, the subsidy amount is EUR 100 per square meter, which reduces payback period.

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The Wien Energie prices are taken as basis for the calculation of the simple return of investment.

Table 22 Energy Prices: Wien Energie (extracted June,2021)

Optima Online Subscription	Energy price (total) in EUR
Basic tariff (EUR/anno)	61.4376
Energy tariff class 1 (0-8000 kWh)	6.8282
Energy tariff class 2 (8001-40000 kWh)	6.8282
Energy tariff class 3 (40001-400000 kWh)	6.1614

Because of the EUR 100 subsidy, the investment cost per square meter has been reduced to approximately EUR 380. Total renovation investment was €647,732.75

Table 23 Simple ROI results

Apartment	Investment	Yearly savings				ROI
	[€]	[kWh]	[kWh.m^{-2}]	[€]	[€.m^{-2}]	[anno]
S1.9	10,629.81	1,378.17	49.29	93.99	€3.36	113.1
S2.3	20,769.18	2,344.51	42.92	159.90	€2.93	129.9
S3.6	24,589.98	3,207.67	49.59	218.76	€3.38	112.4
S4.4	20,674.14			-	-	
S4.5	10,709.64			-	-	
S4.6	20,674.14	1,098.00	20.19	74.88	€1.38	276.1

The simple ROI calculation indicates an average return of investment of 156 years for the apartments with available energy bills. It is a rather high expectation for a refurbishment, however, to calculate a more realistic ROI value it is required to include the building in its entirety. Previously mentioned studies indicated ROIs of 3.1 to 104 heating seasons/years.

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4 CONCLUSION

A key scope behind the present thesis was to identify whether the implemented retrofit has reached the expected energy reduction goals. The proposed assessment brings results analogous to already existing research within the topic of performance improvement after renovation, reproducing a deviation from its expected energy reduction goals.

It could be argued that the potential to ameliorate the energy efficiency of the Am Freihof 33 building is pointed out by the increased energy performance gap. Deterministic modelling in building simulations is the tool used in determining the expected energy demand in this project, although certain studies would recommend stochastic approaches when investigating the potential of the energy performance gap (abbreviated as EPG). A more accurate determination of the energy performance gap would require a detailed study involving the majority tenants, which unfortunately has proven to be a logistical challenge due to the lack of interest, followed by privacy protection issues.

Initial simulations have been carried out through a combination between elaborated occupancy schedules and data from the ASHRAE Standards, which during the calibrations have proven to lack objectivity (occupancy schedules based on anecdotal evidence from the interviews). Through a dynamic simulation and new adjustments to the initial EnergyPlus files, it has been decided to benchmark the ÖNORM B8110-3 as the main standard for the user behaviour indicators, this way performing a so-called data clean-up. Another important milestone in attempting to identify the EPG was the Normalization (or correction of weather files to include the real climate data for the years 2017 and 2018).

Regardless of the information shortage on the achieved performance of the retrofit measures, the municipality of Vienna is nevertheless interested in bettering the city's building fond. Such projects are seen as long-term investment and play an essential social aspect. The main objective of such ongoing renovations, aside from the reduction of energy consumption, is improving the well-being of the citizens and making Vienna a comfortable destination for the workforce; moreover, with such investments the municipality creates jobs in the building sector and guarantees a higher income in taxes thanks to increasing population and rent prices in renovated buildings.

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Despite the challenges that have occurred during the collection of pre- and post-retrofit energy bills, the people willing to participate in this project have made ground for a qualitative comparison of the consumed energy. However, it was a passive involvement, indicating the need of creating strategies in educating and raising the inhabitants' awareness about energy efficiency. An effective way to do it could be the involvement of specialized agencies or even the academia in elaborating a Post Occupancy Evaluation (abbreviated as POE). The main purpose should be to inform about the positive effect a responsible user can have on the environment and quantify through such studies the wasted potential of saving money.

4.1 Limitations of this study

Certain factors have pinpointed objective and subjective limitations to this study. A challenge repeatedly occurring during the study is the sample size, which was limited to 12 people (6 apartments). Even though it represents about 30% of the participation potential, an active involvement could certainly bring more palpable results. Additionally, the participants have showed contrasting understanding of their role in the energy saving potential, indicating a distinctive set of individuals (also by age, gender, nationality, occupancy) and varying awareness within this topic.

Another limitation to this study is the used method in collecting data. The chosen approach, i.e., through direct contact, cannot guarantee a sufficient amount of information. The bureaucratical approach to soliciting data from energy suppliers, the lack of cooperation from tenants and data privacy laws have made it impossible to attain energy consumption data even when soliciting it for research purposes.

Also, the reasoning behind data gaps or missing consumption information for certain years, is explained by the inability from some participating tenants to provide a concise amount of information.

Quintessential for this study was the comparison of the consumed data with the simulation results reached using the climate data. This step of gaining the right climate files also requires a considerable amount of time and know-how. The climate files have been therefore limited to two consecutive years.

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4.2 Future research

By contemplating previous research and the current contribution to the topic of energy performance assessment pre- and post-retrofit, it would be advised to analyse renovations by **being an observer from the initiation of the inquiry to the end of the initial commissioning**. Moreover, the involvement in such projects should start with the monitoring of the energy consumption - a considerable time before as well as after the changes have been made to the envelope and/or heating system. Such an approach can guarantee a more rigorous fact-based and non-biased result analysis.

Access to information is crucial in such projects. It is necessary to elaborate constructive tools that could help attain energy consumption data for research purposes, at times even through bypassing the owners of this information. This might be possible only in the case of non-disclosure of identity. Such topics, i.e., regarding personal data, are very sensible and may lead to the need of adapting legislation. Nevertheless, the main argument towards the access of information is the possibility of improving the way buildings are renovated; and finding ways to reduce expenditure (which is an esteemed intention).

A more thorough evaluation would require a larger study, by **engaging monitoring devices** to understand the effect made on the indoor climate after renovation and the conditions before renovation.

Another interesting idea for future research could be, in contrary, identifying an approach in which the **participation of the building users is kept at a minimum but diverse** (e.g., seeking certain dwellers based on their location in the building, or based on their typology) which can be identified through elaborating the right questionnaires and interviewing.

An important aspect in retrofits is the rebound effect noticed after the completion of projects. One way of preventing such an undesirable consequence is educating the involved stakeholders. It is often the case that the building users do not have the necessary **awareness when it comes to ways of preserving energy**. It is therefore essential to educate the users about the methods in reducing their footprint (e.g., through explaining what thermostats do; or what the purpose of external sun shading is; provision of smart metering) and to offer them a greater clarity of consumption behaviour.

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5 INDEX

5.1 List of Abbreviations

ACH	Air Change per Hour
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BST	Building Science and Technology
DIN	Deutsche Institut für Normung (German Institute for Standardization)
DHW	Domestic Hot Water
EN	European Norm
EPG	Energy Performance Gap
EU	European Union
HD	Heating Demand
HD_{Total}	Total heating demand
nZEB	nearly Zero Energy Building
ÖNORM	österreichische Norm (Austrian Norm)
POE	Post Occupancy Evaluation
ROI	Return of Investment
SAP	Standard Assessment Procedures

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7 APPENDIX

7.1 Tables

Table 24 Eurostat: Final consumption in thousand tonnes of oil equivalent per building sector

Eurostat Data, 2021 (extracted 2021)

https://ec.europa.eu/eurostat/databrowser/view/ten00124/default/table?lang=en

Sector	Thousand tonnes of oil equivalent	Percentile rate, % of the Final consumption
Final Consumption - energy use	935495.04	*not applicable*
Final Consumption - other sectors - commercial and public services - energy use	128538.01	13.7%
Final Consumption - other sectors - households - energy use	245855.83	26.3%
Final Consumption - households and commercial spaces - calc. energy use	374393.84	40.0%

Table 25 Pre-retrofit - U-value calculation - BT1

Bauteil 1	Außenwand 38 Bestand	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1	Innenputz	1,5			0,700		0,021
2	Vollziegelmauerwerk (1500kg/m³)	38,0			0,640		0,594
3	Außenputz	2,5	100,00		0,800		0,031
4							
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							0,816
Wärmedurchgangswiderstand R_T'' in m²K/W							0,816
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,816
Der Bauteil besteht aus 3 homogenen Schichten Gesamtdicke der Konstruktion: 42 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							1,225
Temperaturkorrekturfaktor f_i							1,0

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Table 26 Pre-retrofit - U-value calculation - BT2

Bauteil 2	Außenwand Bestand 25cm	Außenwand

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1	Innenputz	1,5			0,700		0,021
2	Volllochziegelmauerwerk (1500 kg/m³)	25,0			0,640		0,391
3	Außenputz	2,5	100,00		0,800		0,031
4							
5							
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	nicht hinterlüftet	0,170
Wärmedurchgangswiderstand R_T' in m²K/W		0,613
Wärmedurchgangswiderstand R_T'' in m²K/W		0,613
$R_T = (R_T' + R_T'') / 2$ in m²K/W		0,613

Der Bauteil besteht aus 3 homogenen Schichten

Gesamtdicke der Konstruktion: 29 cm

Wärmedurchgangskoeffizient U_i in W/m²K	1,631
Temperaturkorrekturfaktor f_i	1,0

Table 27 Pre-retrofit - U-value calculation - BT3

Bauteil 3	Decke gegen Keller Bestand	Decke zu unbeheiztem Keller

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1	Parkett						
2	Blindboden	2,4			0,150		0,160
3	Beschüttung	8,0	100,00		0,700		0,114
4	Ast-Molin-Decke-Druckplatte	5,0	100,00		2,330		0,021
5	Ast-Molin-Decke-Träger						
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W		0,340
Wärmedurchgangswiderstand R_T' in m²K/W		0,636
Wärmedurchgangswiderstand R_T'' in m²K/W		0,636
$R_T = (R_T' + R_T'') / 2$ in m²K/W		0,636

Der Bauteil besteht aus 3 homogenen Schichten

Gesamtdicke der Konstruktion: 15,4 cm

Wärmedurchgangskoeffizient U_i in W/m²K	1,573
Temperaturkorrekturfaktor f_i	0,5

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Table 28 Pre-retrofit - U-value calculation - BT4

Bauteil 4	Decke gegen Dachraum Bestand	Decke zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Kalkzementmörtel auf Putzträger	2,0			1,000		0,020
3	Meteordecke-Träger	20,0	85,00	15,00	1,110	1,225	0,177
4	Meteordecke-Druckplatte	5,0	100,00		1,110		0,045
5	Beschüttung	8,0	100,00		0,700		0,114
6	Estrich	5,0	100,00		1,400		0,036
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,200
Wärmedurchgangswiderstand R_T' in m²K/W							0,593
Wärmedurchgangswiderstand R_T'' in m²K/W							0,592
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,593
Der Bauteil besteht aus 4 homogenen und 1 inhomogenen Schichten							
Gesamtdicke der Konstruktion: 40 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							1,688
Temperaturkorrekturfaktor f_i							0,9

Table 29 Pre-retrofit - U-value calculation - BT5

Bauteil 5	Feuermauer 25cm Bestand	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4	Außenputz	2,5	100,00		0,800		0,031
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							0,613
Wärmedurchgangswiderstand R_T'' in m²K/W							0,613
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,613
Der Bauteil besteht aus 3 homogenen Schichten							
Gesamtdicke der Konstruktion: 29 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							1,631
Temperaturkorrekturfaktor f_i							1,0

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Table 30 Pre-retrofit - U-value calculation - BT6

Bauteil 6	Feuermauer 38cm Bestand	Wand zu sonstigem Pufferraum

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	38,0	100,00		0,640		0,594
4	Innenputz	1,5	100,00		0,700		0,021
5							
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	0,260
Wärmedurchgangswiderstand R_T' in m²K/W	0,897
Wärmedurchgangswiderstand R_T'' in m²K/W	0,897
$R_T = (R_T' + R_T'') / 2$ in m²K/W	0,897
Der Bauteil besteht aus 3 homogenen Schichten	
Gesamtdicke der Konstruktion: 41 cm	
Wärmedurchgangskoeffizient U_i in W/m²K	1,115
Temperaturkorrekturfaktor f_i	0,5

Table 31 Pre-retrofit - U-value calculation - BT7

Bauteil 7	Wand DG 25cm Bestand	Wand zu unbeheiztem Dachraum

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4							
5							
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	0,260
Wärmedurchgangswiderstand R_T' in m²K/W	0,672
Wärmedurchgangswiderstand R_T'' in m²K/W	0,672
$R_T = (R_T' + R_T'') / 2$ in m²K/W	0,672
Der Bauteil besteht aus 2 homogenen Schichten	
Gesamtdicke der Konstruktion: 26,5 cm	
Wärmedurchgangskoeffizient U_i in W/m²K	1,488
Temperaturkorrekturfaktor f_i	0,9

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Table 32 Pre-retrofit - U-value calculation - BT8

Bauteil 8	Wand DG Kamin Bestand	Wand zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	51,0	100,00		0,640		0,797
4							
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							1,078
Wärmedurchgangswiderstand R_T'' in m²K/W							1,078
$R_T = (R_T' + R_T'') / 2$ in m²K/W							1,078
Der Bauteil besteht aus 2 homogenen Schichten							
Gesamtdicke der Konstruktion: 52,5 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,927
Temperaturkorrekturfaktor f_i							0,9

Table 33 Pre-retrofit - U-value calculation - BT9

Bauteil 9	Wand DG 12cm Bestand	Wand zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	12,0	100,00		0,640		0,188
4							
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							0,469
Wärmedurchgangswiderstand R_T'' in m²K/W							0,469
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,469
Der Bauteil besteht aus 2 homogenen Schichten							
Gesamtdicke der Konstruktion: 13,5 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							2,133
Temperaturkorrekturfaktor f_i							0,9

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Table 34 Pre-retrofit - U-value calculation - BT10

Bauteil 10	Gaupenaußenwand Bestand	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4	Außenputz	2,5	100,00		0,800		0,031
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							0,613
Wärmedurchgangswiderstand R_T'' in m²K/W							0,613
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,613
Der Bauteil besteht aus 3 homogenen Schichten							
Gesamtdicke der Konstruktion: 29 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							1,631
Temperaturkorrekturfaktor f_i							1,0

Table 35 Pre-retrofit - U-value calculation - BT11

Bauteil 11	Dachschräge Gaupe Bestand	Dachschräge					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	GK-Platten	1,3			0,210		0,062
3	Sparren dazw. Mineralwolle	5,0	10,00	90,00	0,150	0,050	0,833
4	Sparren dazw. Luft	11,0	10,00	90,00	0,150	0,120	0,894
5	Vollschalung	2,4	100,00		0,150		0,160
6	Konterlattung						
7	Ziegeleindeckung						
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,140
Wärmedurchgangswiderstand R_T' in m²K/W							2,168
Wärmedurchgangswiderstand R_T'' in m²K/W							2,090
$R_T = (R_T' + R_T'') / 2$ in m²K/W							2,129
Der Bauteil besteht aus 2 homogenen und 2 inhomogenen Schichten							
Gesamtdicke der Konstruktion: 19,7 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,470
Temperaturkorrekturfaktor f_i							1,0

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Table 36 Pre-retrofit - U-value calculation - BT12

Bauteil 12	Stiegenhaus Außendecke Bestand	Außendecke

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1	Default-Wert	10,0			0,179		0,559
2							
3							
4							
5							
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	nach unten: nicht hinterlüftet	0,210
Wärmedurchgangswiderstand R_T' in m²K/W		
Wärmedurchgangswiderstand R_T'' in m²K/W		0,769
$R_T = (R_T' + R_T'') / 2$ in m²K/W		0,384

Der Bauteil besteht aus 1 homogenen Schicht

Gesamtdicke der Konstruktion: 10 cm

Wärmedurchgangskoeffizient U_i in W/m²K	1,300
Temperaturkorrekturfaktor f_i	1,0

Table 37 Pre-retrofit - U-value calculation - BT13

Bauteil 13	Dachschräge Stiegenhaus Bestand	Dachschräge

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1							
2	GK-Platten	1,3			0,210		0,062
3	Sparren dazw. Mineralwolle	5,0	10,00	90,00	0,150	0,050	0,833
4	Sparren dazw. Luft	11,0	10,00	90,00	0,150	0,120	0,894
5	Vollschalung	2,4	100,00		0,150		0,160
6	Konterlattung						
7	Ziegeleindeckung						
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	nicht hinterlüftet	0,140
Wärmedurchgangswiderstand R_T' in m²K/W		2,168
Wärmedurchgangswiderstand R_T'' in m²K/W		2,090
$R_T = (R_T' + R_T'') / 2$ in m²K/W		2,129

Der Bauteil besteht aus 2 homogenen und 2 inhomogenen Schichten

Gesamtdicke der Konstruktion: 19,7 cm

Wärmedurchgangskoeffizient U_i in W/m²K	0,470
Temperaturkorrekturfaktor f_i	1,0

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Table 38 Pre-retrofit - U-value calculation - BT14

Bauteil 14	Decke über DG Bestand	Decke zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Heraklithplatten EPV	3,5			0,120		0,292
3	Konstruktionsholz dazw. Mineralwolle	5,0	10,00	90,00	0,150	0,050	0,833
4	Konstruktionsholz dazw. Luft	11,0	10,00	90,00	0,150	0,120	0,894
5	Laschen dazw. Luft						
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,200
Wärmedurchgangswiderstand R_T' in m²K/W							2,300
Wärmedurchgangswiderstand R_T'' in m²K/W							2,219
$R_T = (R_T' + R_T'') / 2$ in m²K/W							2,259
Der Bauteil besteht aus 1 homogenen und 2 inhomogenen Schicht							
Gesamtdicke der Konstruktion: 19,5 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,443
Temperaturkorrekturfaktor f_i							0,9

Table 39 Post-retrofit - U-value calculation - BT1

Bauteil 1	Außenwand 38 Saniert	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1	Innenputz	1,5			0,700		0,021
2	Vollziegelmauerwerk (1500kg/m³)	38,0			0,640		0,594
3	Außenputz	2,5	100,00		0,800		0,031
4	EPS-F	16,0	100,00		0,032		5,000
5	Spachtelung+Armierung+Silikatputz	0,6	100,00		0,810		0,007
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							5,824
Wärmedurchgangswiderstand R_T'' in m²K/W							5,824
$R_T = (R_T' + R_T'') / 2$ in m²K/W							5,824
Der Bauteil besteht aus 5 homogenen Schichten							
Gesamtdicke der Konstruktion: 58,6 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,172
Temperaturkorrekturfaktor f_i							1,0

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Table 40 Post-retrofit - U-value calculation - BT2

Bauteil 2	Außenwand Saniert 25cm	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1	Innenputz	1,5			0,700		0,021
2	Volllochziegelmauerwerk (1500 kg/m³)	25,0			0,640		0,391
3	Außenputz	2,5	100,00		0,800		0,031
4	EPS-F+	16,0	100,00		0,032		5,000
5	Spachtelung+Armierung+Silikatputz	0,6	100,00		0,810		0,007
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							5,621
Wärmedurchgangswiderstand R_T'' in m²K/W							5,621
$R_T = (R_T' + R_T'') / 2$ in m²K/W							5,621
Der Bauteil besteht aus 5 homogenen Schichten							
Gesamtdicke der Konstruktion: 45,6 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,178
Temperaturkorrekturfaktor f_i							1,0

Table 41Post-retrofit - U-value calculation - BT3

Bauteil 3	Decke gegen Keller Saniert	Decke zu unbeheiztem Keller					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1	Parkett						
2	Blindboden	2,4			0,150		0,160
3	Beschüttung	8,0	100,00		0,700		0,114
4	Ast-Molin-Decke-Druckplatte	5,0	100,00		2,330		0,021
5	Ast-Molin-Decke-Träger	20,0	15,00	85,00	2,330	0,040	0,522
6	Kellerdämmplatte	3,5	100,00		0,040		0,875
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,340
Wärmedurchgangswiderstand R_T' in m²K/W							4,454
Wärmedurchgangswiderstand R_T'' in m²K/W							2,032
$R_T = (R_T' + R_T'') / 2$ in m²K/W							3,243
Der Bauteil besteht aus 4 homogenen und 1 inhomogenen Schichten							
Gesamtdicke der Konstruktion: 38,9 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,308
Temperaturkorrekturfaktor f_i							0,5

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Table 42 Post-retrofit - U-value calculation - BT4

Bauteil 4	Decke gegen Dachraum Saniert	Decke zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Kalkzementmörtel auf Putzträger	2,0			1,000		0,020
3	Meteordecke-Träger	20,0	85,00	15,00	1,110	1,225	0,177
4	Meteordecke-Druckplatte	5,0	100,00		1,110		0,045
5	Beschüttung	8,0	100,00		0,700		0,114
6	Estrich	5,0	100,00		1,400		0,036
7	Mineralwollplatten kaschiert	20,0			0,040		5,000
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,200
Wärmedurchgangswiderstand R_T' in m²K/W							5,593
Wärmedurchgangswiderstand R_T'' in m²K/W							5,592
$R_T = (R_T' + R_T'') / 2$ in m²K/W							5,593
Der Bauteil besteht aus 5 homogenen und 1 inhomogenen Schichten							
Gesamtdicke der Konstruktion: 60 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,179
Temperaturkorrekturfaktor f_i							0,9

Table 43Post-retrofit - U-value calculation - BT5

Bauteil 5	Feuermauer 25cm Saniert	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau			**Bitte Schichten prüfen!**				
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4	Außenputz	2,5	100,00		0,800		0,031
5			100,00		0,040		
6	Spachtelung+Armierung+Silikatputz	0,6	100,00		0,810		0,007
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							
Wärmedurchgangswiderstand R_T'' in m²K/W							
$R_T = (R_T' + R_T'') / 2$ in m²K/W							
Wärmedurchgangskoeffizient U_i in W/m²K							
Temperaturkorrekturfaktor f_i							1,0

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Table 44 Post-retrofit - U-value calculation - BT6

Bauteil 6	Feuermauer 38cm Bestand	Wand zu sonstigem Pufferraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	38,0	100,00		0,640		0,594
4	Innenputz	1,5	100,00		0,700		0,021
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							0,897
Wärmedurchgangswiderstand R_T'' in m²K/W							0,897
$R_T = (R_T' + R_T'') / 2$ in m²K/W							0,897
Der Bauteil besteht aus 3 homogenen Schichten							
Gesamtdicke der Konstruktion: 41 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							1,115
Temperaturkorrekturfaktor f_i							0,5

Table 45 Post-retrofit - U-value calculation - BT7

Bauteil 7	Wand DG 25cm Saniert	Wand zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
● U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4	Mineralwolle	10,0	100,00		0,040		2,500
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							3,172
Wärmedurchgangswiderstand R_T'' in m²K/W							3,172
$R_T = (R_T' + R_T'') / 2$ in m²K/W							3,172
Der Bauteil besteht aus 3 homogenen Schichten							
Gesamtdicke der Konstruktion: 36,5 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,315
Temperaturkorrekturfaktor f_i							0,9

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Table 46 Post-retrofit - U-value calculation - BT8

Bauteil 8	Wand DG Kamin Saniert	Wand zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	51,0	100,00		0,640		0,797
4	Mineralwolle	10,0	100,00		0,040		2,500
5							
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							3,578
Wärmedurchgangswiderstand R_T'' in m²K/W							3,578
$R_T = (R_T' + R_T'') / 2$ in m²K/W							3,578
Der Bauteil besteht aus 3 homogenen Schichten							
Gesamtdicke der Konstruktion: 62,5 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,279
Temperaturkorrekturfaktor f_i							0,9

Table 47 Post-retrofit - U-value calculation - BT9

Bauteil 9	Wand DG 12cm Saniert	Wand zu unbeheiztem Dachraum					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	12,0	100,00		0,640		0,188
4	Mineralwolle	10,0	100,00		0,040		2,500
5	GK-Platte	1,3	100,00		0,210		0,060
6							
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W							0,260
Wärmedurchgangswiderstand R_T' in m²K/W							3,028
Wärmedurchgangswiderstand R_T'' in m²K/W							3,028
$R_T = (R_T' + R_T'') / 2$ in m²K/W							3,028
Der Bauteil besteht aus 4 homogenen Schichten							
Gesamtdicke der Konstruktion: 24,75 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,330
Temperaturkorrekturfaktor f_i							0,9

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Table 48 Post-retrofit - U-value calculation - BT10

Bauteil 10	Gaupenaußenwand Saniert	Außenwand					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	Innenputz	1,5			0,700		0,021
3	Volllochziegelmauerwerk (1500 kg/m³)	25,0	100,00		0,640		0,391
4	Außenputz	2,5	100,00		0,800		0,031
5	EPS-F	16,0	100,00		0,040		4,000
6	Spachtelung+Armierung+Silikatputz	0,6	100,00		0,810		0,007
7							
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,170
Wärmedurchgangswiderstand R_T' in m²K/W							4,621
Wärmedurchgangswiderstand R_T'' in m²K/W							4,621
$R_T = (R_T' + R_T'') / 2$ in m²K/W							4,621
Der Bauteil besteht aus 5 homogenen Schichten							
Gesamtdicke der Konstruktion: 45,6 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,216
Temperaturkorrekturfaktor f_i							1,0

Table 49 Post-retrofit - U-value calculation - BT11

Bauteil 11	Dachschräge Gaupe Saniert	Dachschräge					
○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K							
◉ U-Wert-Berechnung gemäß Schichtaufbau							
Nr.	**Schichtaufbau** von innen nach außen	**Dicke** cm	**Anteil 1** %	**Anteil 2** %	**λ 1** W/mK	**λ 2** W/mK	**d/λ** m²K/W
1							
2	GK-Platten	1,3			0,210		0,062
3	Sparren dazw. Mineralwolle	14,0	10,00	90,00	0,150	0,040	2,745
4	Sparren dazw. Mineralwolle	8,0	10,00	90,00	0,150	0,040	1,569
5	Vollschalung	2,4	100,00		0,150		0,160
6	Konterlattung						
7	Ziegeleindeckung						
8							
Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W			nicht hinterlüftet				0,140
Wärmedurchgangswiderstand R_T' in m²K/W							5,224
Wärmedurchgangswiderstand R_T'' in m²K/W							4,676
$R_T = (R_T' + R_T'') / 2$ in m²K/W							4,950
Der Bauteil besteht aus 2 homogenen und 2 inhomogenen Schichten							
Gesamtdicke der Konstruktion: 25,7 cm							
Wärmedurchgangskoeffizient U_i in W/m²K							0,202
Temperaturkorrekturfaktor f_i							1,0

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Table 50 Post-retrofit - U-value calculation - BT12

Bauteil 12	Stiegenhaus Außendecke Saniert	Außendecke

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1	Defaultwert	10,0			0,179		0,559
2	Mineralwollplatte	16,0			0,038		4,211
3							
4							
5							
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	nach unten: nicht hinterlüftet	0,210
Wärmedurchgangswiderstand R_T' in m²K/W		
Wärmedurchgangswiderstand R_T'' in m²K/W		4,979
$R_T = (R_T' + R_T'') / 2$ in m²K/W		2,490

Der Bauteil besteht aus 2 homogenen Schichten

Gesamtdicke der Konstruktion: 26 cm

Wärmedurchgangskoeffizient U_i in W/m²K	0,201
Temperaturkorrekturfaktor f_i	1,0

Table 51 Post-retrofit - U-value calculation - BT13

Bauteil 13	Dachschräge Stiegenhaus Saniert	Dachschräge

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1							
2	GK-Platte	1,5			0,210		0,071
3	Sparren dazw. Mineralwolle	3,0	10,00	90,00	0,150	0,040	0,588
4	Sparren dazw. Luft	11,0	10,00	90,00	0,150	0,040	2,157
5	Vollschalung	2,4	100,00		0,150		0,160
6	Vordeckung						
7	Konterlattung, Lattung, Dachdeckung						
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	nicht hinterlüftet	0,140
Wärmedurchgangswiderstand R_T' in m²K/W		3,419
Wärmedurchgangswiderstand R_T'' in m²K/W		3,117
$R_T = (R_T' + R_T'') / 2$ in m²K/W		3,268

Der Bauteil besteht aus 2 homogenen und 2 inhomogenen Schichten

Gesamtdicke der Konstruktion: 17,9 cm

Wärmedurchgangskoeffizient U_i in W/m²K	0,306
Temperaturkorrekturfaktor f_i	1,0

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Table 52 Post-retrofit - U-value calculation - BT14

Bauteil 14	Decke über DG Saniert	Decke zu unbeheiztem Dachraum

○ U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K

◉ U-Wert-Berechnung gemäß Schichtaufbau

Nr.	Schichtaufbau von innen nach außen	Dicke cm	Anteil 1 %	Anteil 2 %	λ 1 W/mK	λ 2 W/mK	d/λ m²K/W
1							
2	Mineralwollplatten kaschiert	20,0			0,040		5,000
3	Konstruktionsholz dazw. Mineralwolle	5,0	10,00	90,00	0,150	0,050	0,833
4	Konstruktionsholz dazw. Luft	11,0	10,00	90,00	0,150	0,120	0,894
5	Laschen dazw. Luft						
6							
7							
8							

Wärmeübergangswiderstände $R_{si} + R_{se}$ in m²K/W	0,200
Wärmedurchgangswiderstand R_T' in m²K/W	7,025
Wärmedurchgangswiderstand R_T'' in m²K/W	6,928
$R_T = (R_T' + R_T'') / 2$ in m²K/W	6,976

Der Bauteil besteht aus 1 homogenen und 2 inhomogenen Schicht

Gesamtdicke der Konstruktion: 36 cm

Wärmedurchgangskoeffizient U_i in W/m²K	0,143
Temperaturkorrekturfaktor f_i	0,9

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Table 53 Energy Bills Data (Detailed) (1/2)

Climate zone/Apartment	Surface area [m-2]		Occupancy [people]	Energy Demand (Y.2013-Y.2014)		Energy Demand (Y.2014-Y.2015)	
	acc. Floor plans (Netto)	acc. E+ (Brutto)		**Total demand**	per sq. m.	**Total demand**	per sq. m.
S1.9	27.96 m-2	32.92 m-2	1	**4,871.00 kWh**	174 kWh.m-2		
S2.3	54.63 m-2	60.77 m-2	1			**7,684.00 kWh**	141 kWh.m-2
S3.6	64.68 m-2	71.98 m-2	1	**8,936.00 kWh**	138 kWh.m-2	**8,876.00 kWh**	137 kWh.m-2
S4.4	54.38 m-2	72.04 m-2	4				
S4.5	28.17 m-2	36.75 m-2	3				
S4.6	54.38 m-2	58.89 m-2	4			**4,491.00 kWh**	83 kWh.m-2

Table 54 Energy Bills Data (Detailed) (2/2)

Climate zone/Apartment	Energy Demand (Y.2015-Y.2016)		Energy Demand (Y.2016-Y.2017)		Energy Demand (Y.2017-Y.2018)		Energy Demand (Y.2018-Y.2019)	
	Total demand	per sq. m.	**Total demand**	per sq. m.	**Total demand**	per sq. m.	**Total demand**	per sq. m.
S1.9	**3,658.00 kWh**	131 kWh.m-2	**2,271.00 kWh**	81 kWh.m-2	**2,953.00 kWh**	106 kWh.m-2	**3,435.00 kWh**	123 kWh.m-2
S2.3	**5,547.00 kWh**	102 kWh.m-2	**4,229.97 kWh**	77 kWh.m-2	**4,312.01 kWh**	79 kWh.m-2		
S3.6	**6,891.00 kWh**	107 kWh.m-2	**5,386.00 kWh**	83 kWh.m-2	**4,740.00 kWh**	73 kWh.m-2	**4,954.00 kWh**	77 kWh.m-2
S4.4					**5,607.00 kWh**	103 kWh.m-2	**5,211.00 kWh**	96 kWh.m-2
S4.5							**3,360.00 kWh**	119 kWh.m-2
S4.6	**6,251.00 kWh**	115 kWh.m-2	**4,273.00 kWh**	79 kWh.m-2				

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Table 55 DHW and Energy Demand for Space Heating

Climate zone/Apartment		DHW	Space Heating	DHW [in %]	Space heating [in %]
S1.9	Pre-	27 kWh.m-2	125 kWh.m-2	18%	82%
	Post-	27 kWh.m-2	76 kWh.m-2	27%	73%
S2.3	Pre-	14 kWh.m-2	107 kWh.m-2	12%	88%
	Post-	14 kWh.m-2	64 kWh.m-2	18%	82%
S3.6	Pre-	12 kWh.m-2	115 kWh.m-2	9%	91%
	Post-	12 kWh.m-2	66 kWh.m-2	15%	85%
S4.4	Pre-				
	Post-	14 kWh.m-2	85 kWh.m-2	14%	86%
S4.5	Pre-				
	Post-	27 kWh.m-2	92 kWh.m-2	23%	77%
S4.6	Pre-	14 kWh.m-2	85 kWh.m-2	14%	86%
	Post-	14 kWh.m-2	64 kWh.m-2	18%	82%

Table 56 Simulation Results: Adjustments 1 + 2. District Heating Intensity per conditioned floor area (Detailed) (1/2)

District Heating Intensity per Conditioned Floor Area [kWh.m-2]				S1.9				S2.3				S3.6			
#	Adjustment	Calibration	Description	Before Ren.		After Ren.		Before Ren.		After Ren.		Before Ren.		After Ren.	
				B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE
1.	Adjustment 1	Activity & occupancy schedules (acc. to tenant inteviews)	Activitiy schedules and occupancies determined following interviews with the building users	-	160.91	-	54.97	-	85.63	-	37.86	-	148.39	-	68.77
2.	Adjustment 2	New Schedules - Internal Gains (acc. to the ÖNORM B8110)	The Activity Schedules have been adapted to the values in B-8110-3:2020 and ASHRAE Table 2 - People Heat Gains; Table 3 - Equipment Heat Gains	147.42	-	44.44	-	68.6	-	23.47	-	139.69	-	61.06	-
3.		Natural Ventilation Simulated (Setpoint = 20°C)	ZoneVentilation:DesignFlowRate added to the E+ Simulation; Values from B-8110-3:2020 (Heatingsetpoint 20deg.C) Table 4 Specific Hygienic Air Flow in naturally ventilates spaces	164.18	178.1	59.87	71.67	84.56	102.37	38.11	54.1	155.69	164.67	76.54	84.67
4.		Heating Setpoint - 18 °C	18 °C	122.54	134.83	36.09	45.54	56.1	71.96	18.36	31.48	117.4	125.42	51.18	58.07
5.		Heating Setpoint - 19 °C	19 °C	134.8	147.68	40.7	50.54	62.41	78.81	21.38	34.96	128.45	136.79	56.53	63.59
6.		Heating Setpoint - 21 °C	21 °C	184.52	199.74	70.31	82.64	97	115.77	46.15	63.09	174.15	184.03	87.59	96.19

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Table 57 Simulation Results: Adjustments 1 + 2. District Heating Intensity per conditioned floor area (Detailed) (2/2)

District Heating Intensity per Conditioned Floor Area [kWh.m-2]				S4.4				S4.5				S4.6			
#	Adjustment	Calibration	Description	Before Ren.		After Ren.		Before Ren.		After Ren.		Before Ren.		After Ren.	
				B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE	B8110	ASHRAE
1.	Adjustment 1	Activity & occupancy schedules (acc. to tenant inteviews)	Activitiy schedules and occupancies determined following interviews with the building users	-	75.27	-	27.24	-	215.77	-	64.59	-	127.23	-	41.25
2.	Adjustment 2	New Schedules - Internal Gains (acc. to the ÖNORM B8110)	The Activity Schedules have been adapted to the values in B-8110-3:2020 and ASHRAE Table 2 - People Heat Gains; Table 3 - Equipment Heat Gains	68.86	-	24.31	-	192.53	-	45.28	-	119.52	-	35.1	-
3.		Natural Ventilation Simulated (Setpoint = 20°C)	ZoneVentilation:DesignFlowRate added to the E+ Simulation; Values from B-8110-3:2020 (Heatingsetpoint 20deg.C) Table 4 Specific Hygienic Air Flow in naturally ventilates spaces	81.83	91.63	36.49	42.87	211.19	235.16	62.73	83.26	135.97	143.89	50.26	57.16
4.		Heating Setpoint - 18 °C	18 °C	56.91	62.28	19.71	21.81	160.54	181.42	36.36	54.35	99.36	106.3	28.1	33.53
5.		Heating Setpoint - 19 °C	19 °C	62.98	68.83	22.72	25.17	176.27	198.09	41.17	59.61	109.38	116.73	31.94	37.82
6.		Heating Setpoint - 21 °C	21 °C	92.87	104.33	43.25	50.94	236.09	262.54	73.85	95.64	152.84	161.5	59.58	66.91

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Table 58 Simulation Results: Adjustments 3 (Detailed)

Climate zone/Apartment		Simulation (Benchmark)	Normalization	Calibration (ACH=0,6)	Calibration (ACH=0,8)
S1.9	Pre-	147.3 kWh.m-2			
	Post-	43.6 kWh.m-2			
	Y.2017		32.2 kWh.m-2	43.1 kWh.m-2	54.9 kWh.m-2
	Y.2018		32.3 kWh.m-2	43.2 kWh.m-2	55.0 kWh.m-2
S2.3	Pre-	78.6 kWh.m-2			
	Post-	23.5 kWh.m-2			
	Y.2017		16.3 kWh.m-2	25.8 kWh.m-2	36.1 kWh.m-2
	Y.2018		16.2 kWh.m-2	25.7 kWh.m-2	36.0 kWh.m-2
S3.6	Pre-	139.7 kWh.m-2			
	Post-	61.1 kWh.m-2			
	Y.2017		48.6 kWh.m-2	61.2 kWh.m-2	74.2 kWh.m-2
	Y.2018		48.8 kWh.m-2	61.5 kWh.m-2	74.5 kWh.m-2
S4.4	Pre-	68.9 kWh.m-2			
	Post-	24.3 kWh.m-2			
	Y.2017		18.2 kWh.m-2	26.8 kWh.m-2	36.1 kWh.m-2
	Y.2018		18.2 kWh.m-2	26.8 kWh.m-2	36.2 kWh.m-2
S4.5	Pre-	192.5 kWh.m-2			
	Post-	45.3 kWh.m-2			
	Y.2017		33.8 kWh.m-2	46.2 kWh.m-2	58.7 kWh.m-2
	Y.2018		33.8 kWh.m-2	46.3 kWh.m-2	58.9 kWh.m-2
S4.6	Pre-	119.5 kWh.m-2			
	Post-	35.1 kWh.m-2			
	Y.2017		25.7 kWh.m-2	36.6 kWh.m-2	48.1 kWh.m-2
	Y.2018		25.7 kWh.m-2	36.6 kWh.m-2	48.2 kWh.m-2

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Table 59 ROI Calculation table

Apartment	Surface area [m-2]	Energy consumption [kWh]		Energy costs [€]		Investment	Yearly savings				ROI
	acc. Floor plans	pre-retrofit	post-retrofit	pre-retrofit	post-retrofit	[€ Total]	Energy [kWh]	Energy [kWh.m-2]	Financial [€]	Financial [€.m-2]	[anno]
S1.9	27.96 m-2	4,264.50 kWh	2,886.33 kWh	€ 290.84	€ 196.85	€ 10,629.81	1,378.17 kWh	49.29 kWh	€ 93.99	€ 3.36	113.1
S2.3	54.63 m-2	6,615.50 kWh	4,270.99 kWh	€ 451.18	€ 291.28	€ 20,769.18	2,344.51 kWh	42.92 kWh	€ 159.90	€ 2.93	129.9
S3.6	64.68 m-2	8,234.33 kWh	5,026.67 kWh	€ 561.58	€ 342.82	€ 24,589.98	3,207.67 kWh	49.59 kWh	€ 218.76	€ 3.38	112.4
S4.4	54.38 m-2		5,409.00 kWh	€ -	€ 368.89	€ 20,674.14			€ -	€ -	
S4.5	28.17 m-2		3,360.00 kWh	€ -	€ 229.15	€ 10,709.64			€ -	€ -	
S4.6	54.38 m-2	5,371.00 kWh	4,273.00 kWh	€ 366.30	€ 291.42	€ 20,674.14	1,098.00 kWh	20.19 kWh	€ 74.88	€ 1.38	276.1

7.2 Online documentation

The entire Documentation can be found under this OneDrive link:

https://1drv.ms/f/s!AkumlDCeeM7Vh8g1LCMX908ouUJgUA

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WIENER WOHNEN

Stadt Wien – Wiener Wohnen, Rosa-Fischer-Gasse 2, A-1030 Wien

An die
Magistratsabteilung 37

Stadt Wien – Wiener Wohnen
Koordinationsbereich Immobilienmanagement
Fachbereich Baumanagement
Dezernat Bauprojektabwicklung

Rosa-Fischer-Gasse 2, A - 1030 Wien
Tel.: 05 75 75 75; Fax: 05 75 75 99-52 810
E-Mail: bk@wrw.wien.gv.at
Homepage: www.wienerwohnen.at

Bezug (Geschäftszahl, Schreiben vom)	Referat/Sachbearbeiter/in
Vollmacht	KROPIK
Geschäftszahl, Betreff	Datum
Planeinsichtnahme	21.01.2019

Sehr geehrte Damen und Herren!

Die Unternehmung Stadt Wien - Wiener Wohnen erteilt Herrn Cristian Casian, geboren am 10.06.1993 die Vollmacht zur **Besichtigung und Dokumentation der Wohnhausanlage** und **Einsicht in die Bauakte/die Hauseinlage der unten angeführten Objekte bei der MA 37** – Baupolizei, sowie bei Erfordernis die Erlaubnis zur Erstellung von Kopien und Scanvorgängen.

Diese Vollmacht ist gültig bis: 30.06.2019

Gegenständliche Wohnhausanlage:

23., Breitenfurterstraße 242 (EZ 12, KG Atzgersdorf (01801), Grundstücksnummer: 39)
6., Dominikanergasse 5 (EZ 112, KG Mariahilf (01009), Grundstücksnummer: 969)
22., Am Freihof 33 (EZ 19, KG Kagran (01660), Grundstücksnummer: 68/1)

Mit freundlichen Grüßen
Für die Direktorin

DI^in Bettina Kropik
Referatsleitung

STADT WIEN
WIENER WOHNEN
1030 Wien, Rosa-Fischer-Gasse 2
DVR: 0000191

Figure 39 Power of Attorney for visiting the objects (Wiener Wohnen)

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FO - 0355/2010 WK/HP

MA 50 - Schli-II/5638/2010

PRÜFBERICHT NR. 01 vom 18.06.2012

Gebührenbefreit gemäß § 42 WSG

1220 Wien, Kraygasse 89
ident: Am Freihof 33
EZ 00019 / KG Kagran

Antragsdatum: 01.09.2010

fonds für wohnbau und stadterneuerung

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a-1082 wien

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f: +43 (0)1 403 59 19-86659

e: office@wohnfonds.wien.at
i: www.wohnfonds.wien.at

dvr: 0454842

Förderungsvoraussetzungen
auf Basis des Vorprüfberichtes vom 14.05.2012
inkl. Stellungnahme gem. § 38 MRG und Gutachten

1.0. Förderungswerber:	Stadt Wien 1082 Wien, Neues Rathaus
1.1. Rechtsstellung Förderungswerber:	Alleineigentümer lt. GBA vom 13.06.2012
1.2. Bevollmächtigter:	Arch. DI Vera Korab ZT-GmbH Staatl. befugte und beeidete Ziviltechnikerin 1220 Wien, Hirschstettner Straße 19-21/J/DG Tel. 280 02 70
1.3. Baubetreuer:	Arch. DI Vera Korab ZT-GmbH Staatl. befugte und beeidete Ziviltechnikerin 1220 Wien, Hirschstettner Straße 19-21/J/DG Tel. 280 02 70
2.0. Förderungsbegehren:	Gewährung einer Förderung gemäß § 40 WWFSG 89 zur Durchführung von Sanierungsmaßnahmen an und in einem Gebäude im Sinne § 37 WWFSG 89.
Sanierungsart:	Thermisch-energetische Sanierung eines Gebäudes, in dem Wohnungen der Kategorie **B** überwiegen in Verbindung mit Sanierungsverordnung LGBl.Nr. 2/2009 idF. 27/2009 § 5 (TheWoSan - umfassend) § 8 Abs.4 Z.2 (Erhaltung mit THEWOSAN, EM10 J)

Figure 40 Energy Audit of the Am Freihof 33 renovation proposal

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Staatl. befugte und beeidete Ziviltechnikerin

BAUPHYSIKALISCHE BERECHNUNG FÜR DIE THERMISCH-ENERGETISCHE WOHNHAUSSANIERUNG

Objekt:	Wohnhausanlage Kraygasse 89 1220 Wien EZ: 19 KG: 01660 Kagran Grst.Nr.: 68/1
Auftraggeber:	Wiener Wohnen Koordination Technik Bereich Immobilienmanagement Rosa-Fischer-Gasse 2 1030 Wien

Hirschstettner Straße 19-21/J/DG, 1220 Wien ■ Tel.: 01/280 02 70 ■ Fax: DW 14 ■ E-Mail: office@archkorab.at ■ Web: www.archkorab.at
■ Bankverbindung: BA-CA 51558012101, BLZ 12000 ■ ERSTE 05147727, BLZ 20111 ■ FN-Nr. 228338t ■ UID-Nr. ATU56671667

Figure 41 Building Physics Calculations of the pre- and post-retrofit conditions (DI Vera KORAB ZT GmbH)

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