Evaluation of Residential Real Estate Energy-Rating Systems in Germany, and their Applicability to the United States

By

Felix Naerger

Bachelor of International Relations and Business Administration, IE University (2020)
Master in Management, HEC Paris (2023)

SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF

MASTER OF SCIENCE IN MANAGEMENT STUDIES

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2023

Authored by: Felix Naerger
MIT Sloan School of Management
May 12th, 2023

Certified by: Walter Torous
Senior Lecturer, MIT Center for Real Estate & Sloan School of Management
Thesis Supervisor

Accepted by: Jacob Cohen
Senior Associate Dean for Undergraduate & Masters' Program

Evaluation of Residential Real Estate Energy-Rating Systems in Germany, and their Applicability to the United States

By

Felix Naerger

Submitted to the MIT Sloan School of Management on May 12, 2023 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Management Studies.

ABSTRACT

Energy efficiency has become an increasingly important topic as economies globally race to combat climate change. Real estate is a major driver of global emissions, however also a key potential area for emissions reductions.

In Germany, residential real estate has been identified as a major source potential of emissions savings, given the impact of the sector. As such, energy efficiency systems have been implemented, providing transparency for property owners and renters. Motivated by cost-savings, the aspects of these systems pertain to energy production, energy mix use, and heating efficiency.

The United States as a country differs too strongly to allow for blind copying of the system in place in Germany. Its geographic size, climatic range, and population densities require a system of its own. Nevertheless, the lessons learnt from the German systems can help inspire initial steps towards effective American systems.

Thesis supervisor: Walter Torous
Title: Senior Lecturer, MIT Center for Real Estate & Sloan School of Management

Acknowledgements

I would like to express my deepest thanks to my thesis supervisor, Professor Torous. He has provided me with the inspiration for this exciting topic, enabling me to build upon my quantitative experience in Real Estate, and further my knowledge also in qualitative regions. This has allowed me to develop this thesis in an area of research which I find both relevant and important.

Table of Contents

Introduction

Background and Context of Research

There exists an increasing pressure on governments across the globe to commit to a green energy transition, and more so, a reduction of greenhouse gas emissions. The undeniable link between carbon emissions and climate change has led this push, with numerous stakeholders across society increasing the pressure on their elected leaders.[1] A major milestone in political decision-making was the 2015 Paris Agreement, which seeks to limit global temperature increase to 2 degrees Celsius within this century, whilst advocating additional efforts to keep this heating within the 1.5 degrees Celsius range.[2] A further example can be found with the International Energy Agency, who put forth a 'Net Zero Emissions' scenario which provides guidance on how the global energy sector can achieve net zero carbon emissions by 2050.[3]

To achieve these goals in global emissions there exist two major levers.
Firstly, energy production can 'go green', whereby a shift is made away from traditional hydrocarbon sources towards renewables such as solar, hydropower, wind, geothermal, and to some debate, nuclear. This lever ensures that of our current global energy requirement, an increasing portion stems from sustainable sources which do not release greenhouse gases, and thereby the energy production does not contribute to global emissions.
The second lever is efficiency. Energy efficiency refers to utilizing less energy for the accomplishment of the same task, or to achieve the same level of output. There exist numerous areas in modern society for enhancing efficiency, from optimized logistic supply chains, improved manufacturing processes, advancements in materials and technology, but also within real estate.

Environmentally, real estate is a major factor given the sector's global emissions impact (detailed discussion to follow). Thus, it is of interest to understand what systems and structures government bodies have implemented to restrict emissions within the

---

[1] A notable example would be the "Fridays for Future" protests, which were found across Europe prior to the Covid-19 pandemic.
[2] (United Nations, 2021)
[3] (International Energy Agency, 2022)

residential sector, and provided incentives to increase efficiency. These efforts are not only relevant from a purely environmental perspective, but also pertain to areas such as property value, living costs, and drivers of renovations.

Research Question

This overview of the importance of residential real estate efficiency leads to the question at hand; What prominent residential efficiency standards exist, and how can these serve as inspiration to areas where such standards are not yet found? This exploratory paper will aim to understand a major European country's efficiency system, namely that of Germany. Understanding its development, critiques, and future outlook, insights will be drawn as to how a residential efficiency system in the United States could be comprised, and what structural differences exist between the United States and this European region.

Significance and Contribution of Research

Although this author unfortunately lacks the means to directly solve any efficiency shortfalls in American residential real estate, this paper aims at sparking conversation as to the design considerations an American system may benefit from. This aims to assist various stakeholders in the American residential real-estate market, from property owners to renters, developers, and sources of financing.

Overview of Thesis Structure

This paper will begin by outlining the role of emissions from real estate, to better understand the relevance of this topic. Then, the focus will shift towards the European residential efficiency system in Germany. Its state as is, past developments, current criticisms, and future outlooks will be discussed to develop a solid understanding of what factors affect their development. Lastly, the structure of residential real estate in the United States will be compared to that in the aforementioned country. This will serve as a basis for making considerations as to an American system.

Methodology

Firstly, existing literature will be reviewed. The goal is to understand the role of building efficiency, especially within the residential sector. This relationship is important, as it pertains to the relevance of energy efficiency as a market dynamic in real estate. On one hand energy efficiency is a cost-saving mechanism, however it is also a signaling mechanism. Understanding whether efficiency is valued by the market, and thus reflected in higher rents and transaction prices, directly impacts the utility of a potential residential energy rating system for the United States.

After having established this dynamic, a market analysis of Germany will be completed. This analysis will look into the energy sources of the country, and the energy uses of residential real estate. Furthermore, structural aspects of the residential sector will be uncovered. Understanding these market characteristics will be important when we later wish to prompt considerations for a potential rating system in the United States.

Furthermore, the rating system in place in Germany will be discussed. Its past developments, current status, and ongoing development will be taken into account, aiming to enable a well-grounded discussion of their applicability toward the United States.

Lastly, this paper will conclude with insights for a United States residential property energy rating system. By applying the knowledge gathered and examining the structure of the United States' residential market, feasible and rational guidance will be put forward.

Literature Review

This paper is primarily geared towards examining the energy rating systems for residential real estate. However, before examining the individual rating systems and the structural realities that shape them, it appears wise to validate whether building efficiency and energy ratings are reflected in the real estate market, namely in real estate pricing. This looks beyond the basic emission taxation an energy policy might entail, namely how home (and rental) prices incorporate energy efficiency ratings in terms of cost-savings and market premiums.

To begin with, Taruttis and Weber (2022)[4] find that a decrease in energy consumption (measured as kWh/m^2) increases the asking-price for single-family homes in Germany. Their findings are confirmed when looking at energy consumption from a ratings perspective (A+ to H). Namely, retrofitting inefficient homes (measured as an ascent up the efficiency rating scale) results in a price appreciation, however only for less-efficient houses where efficiency gains are greatest and a cost-efficient investment.
This limitation was previously noted by Holm et al. (2015)[5], who examined the amortization period of various thermal insulation investments.[6] With amortization periods of 7 to 26 years (depending on the investment undertaken), investments only enhance value if notable cost-savings can be realized.

A similar relationship between energy efficiency and higher home values was found by Fuerst et al. (2015)[7] when examining residential real estate in England. A measurable and significant impact between energy efficiency labels and house prices was found. A less clear yet nevertheless positive relationships could also be established between positive efficiency labels and the growth in house prices; implying that strong efficiency fundamentals provide improved growth rates.

[4] (Taruttis & Weber, 2022)
[5] (Holm, Mayer, & Sprengrad, 2015)
[6] Although this paper is limited to thermal insulation improvements, later discussion in this paper will clarify that heating is the major energy consumption factor in German housing. Thus, although of reduced scope, these findings are still relevant.
[7] (Fuerst, McAllister, Nanda, & Wyatt, 2015)

Further studies for European markets concluded similar positive relationships between energy efficiency and home prices. A study prepared for the European Commission in 2013 stated that transactions within "residential property markets in Austria, Belgium, France, Ireland and the UK, both sales and lettings, overwhelmingly point to energy efficiency being rewarded by the market" (Mudgal, Lyons, Cohen, Lyons, & Fedrigo-Fazio, 2013). The results should not be interpreted as being limited to the mentioned countries, as they were simply those within the scope of research.

Furthermore, Taruttis and Weber (2022) also address whether using the guidance of an energy rating system differs from simply looking at historic consumption data. They demonstrate via the German market that the previously outlined price-appreciating impact of higher efficiency is stronger when building efficiency is proven via a rating certificate. They postulate that home buyers value high energy efficiency less when it is based on the energy consumption data of the previous owner, reasoning that most home buyers find it difficult to superimpose their personal energy use (heating, cooling, lighting, etc.) on the historic data of a seller, versus comparing to a standardized rating system.

Shifting towards the United States, the existing literature suggests that energy efficiency is likewise rewarded by the country's market. A paper published in 2017 analyzing 10 cities in the United States found that rental apartments which listed energy efficient features (such as appliance upgrades, insulation, and lighting instalments) saw a significant increase in rental prices, also translating to higher property value.[8]

To summarize the above, we have found in the established literature a repeated link whereby energy efficiency translates into higher rents and transaction prices. Energy efficiency in the form of a certificate strengthens this trend, as it removes assumptions for renters/buyers, compared to relying on historical energy usage information. Lastly, energy efficient improvements create the most value when large efficiency gains can be made, and the higher savings result in a shorter pay-back period.

[8] (Im, Seo, Cetin, & Singh, 2017)

Market Examination

Efficiency in real estate has increasingly become a pressing question, especially given the sizeable impact the sector has on global emissions. Globally, approximately 39% of emissions are driven by the real estate sector.[9] Whilst 11% of this stems from construction and material usage, the remaining 28% of global emissions result from the operation of the properties themselves and the energy required to power them. Heating, cooling, lighting, amenities; all these uses of power enable houses and apartments to function smoothly and provide high quality of life.

It is important to note that some sources may claim a slightly different figure. One report suggests that building operations are responsible for *just* 17.5% of global emissions.[10] However, the initially stated values (39%; 28%) are proposed by a wide array of reputable sources (including the German Environmental Ministry[11]), and any deviations are the result of how one cuts the data; e.g. inclusion of logistics in construction vs. solely measuring the raw materials used. What should stand out across different sources is the large energy consumption which real estate represents.

Given this impact of real estate, and the goal of increased energy efficiency initially outlined, it comes as no surprise that many countries have begun implementing efficiency standards for real estate. Politically, achieving gains in emissions reductions via the real estate sector has been of increasing focus. The German Environmental Agency (*Umweltbundesamt, UBA*) under Steffi Lemke (Greens Party) recently released a Position Paper, in which the focus lay on sustainable residential and public construction.[12] It renewed the interest in developing long-term strategies for sustainable development, with a core focus on environmental aspects (others being social equality, livable cities, and more).

Before examining the specific residential rating system in place in Germany, it is important to develop an understanding of its energy and housing landscape. For this, the residential housing structure, energy production, and energy usage will be examined.

---

[9] (Boland, Levy, Palter, & Stephens, 2022)
[10] (Ritchie, Roser, & Rosado, 2020)
[11] (Umwelt Bundesamt (Federal Ministry for the Environment), 2022)
[12] (Frank, 2023)

German Residential Real Estate Landscape

Population and Residential Real Estate Mix

Serving the population of 84.3 million Germans, there exist roughly 43 million apartments and homes (single-family dwellings).[13,14]
The housing mix in terms of families per dwelling is as follows:[15]

Single Homes

This refers to properties which for which at least 50% of the Living Surface Area (measured in m^2) is reserved for living purposes (measured after DIN 227). They are inhabited by a single family / living constellation.

Table 1 - German Single Homes

	Number of Buildings	Total Surface Area (1000 m^2)	Number of Apartments[16]
2018	12,707,978	1,638,840	12,707,978
2019	12,786,505	1,651,599	12,786,505
2020	12,867,447	1,664,613	12,867,447
2021	12,939,452	1,676,403	12,939,452

Dual Family Homes

This refers to properties, which as above reserves at least 50% of the surface area for living purposes. Unlike single homes, the constructed building is occupied by two separate legal families, and the building is separated as to which areas can be accessed by each. A typical constellation found in Germany is the 'Row House' (*Reihenhaus*), which sees one building 'split' down the middle (with a resulting left and right half), resulting in two separate homes within the same building.

[13] (Destatis, 2023)
[14] (Destatis, 2023)
[15] (Destatis, 2022); All dwelling tables pertain to this source.
[16] Here the Number of Buildings and Number of Apartments are equal, as each Single-Home houses only one apartment.

Table 2 - German Dual Family Homes

	Number of Buildings	Total Surface Area (1000 m^2)	Number of Apartments
2018	3,129,233	603,465	6,258,466
2019	3,141,027	606,470	6,282,054
2020	3,153,666	609,668	6,307,332
2021	3,166,047	612,785	6,332,094

Multi-Family Homes

To be understood as an apartment-style building, which houses 3+ families in separate units.

Table 3 - German Multi-Family Homes

	Number of Buildings	Total Surface Area (1000 m^2)	Number of Apartments
2018	3,193,736	1,490,084	21,369,968
2019	3,210,933	1,502,983	21,529,478
2020	3,229,473	1,516,646	21,700,534
2021	3,247,507	1,529,925	21,868,012

Dormitories

Buildings which serve the special needs of certain social groups, such as student residences or senior homes. Each unit is individually occupied an serves and individual household.

Table 4 - German Dormitory Homes

	Number of Buildings	Total Surface Area (1000 m^2)	Number of Apartments
2018	22,269	21,326	492,305
2019	22,512	21,694	502,291
2020	22,700	21,990	510,606
2021	22,905	22,325	521,215

Firstly, one can note that although the number of multi-family (3+) homes is far greater than single/dual homes, in terms of surface area the single-family homes is represent a larger share than multi-family homes.

It is important to note that a large proportion of the single/dual family residential housing occurs in rural areas. By comparison, the percentage of multi-family homes (apartments) was 35.4% in Stuttgart, and 40.1% in Frankfurt, Dusseldorf, and Main.[17] Thus, a materially different mix can be observed in rural and urban areas, which is important to note given the difference in size an average Single/Dual Family Home measures versus Multi-Family Homes.

Secondly, one can observe the trend of building growth across all building types. The figures above represent the net number of buildings; constructions minus demolitions. Demographic pressure has therefore seen a steady expansion of all living arrangements, with no one building type replacing another. However, the higher growth in number of apartments found in Multi-Family homes does speak for a rural-to-urban transition[18], as higher-density buildings are favored.

[17] (Destatis, 2021)
[18] (German Federal Ministry of the Interior, 2012)

German Energy Mix

Moving on from the make-up of the residential property sector, it is important to understand the sources of energy production in Germany. The cleaner the energy being produced, the less urgent high energy efficiency in the residential sector is.

However, as the following table indicates, only 40-44% of electricity production has come from renewable sources in the past years. Importantly, the comparatively clean natural gas of the past has seen a recent decline given an import stop from Russia, following the Ukraine invasion and subsequent sanctioning. This has led to a higher reliance on coal – especially the high-emission lignite prominent in Germany.[19]

More so, Germany has in 2023 taken its remaining three nuclear power plants off the grid.[20] This development was started following the Fukushima Nuclear Reactor Incident in Japan in 2011. This transition has been heavily debated, as alternative renewable energy sources have not been deployed rapidly enough to substitute and grow beyond the nuclear-derived power, and thus Germany continues to rely on non-renewable sources. However, the Free Democratic Party in Germany is fighting to maintain these three nuclear reactors as a reserve, rather than have them fully removed.[21]

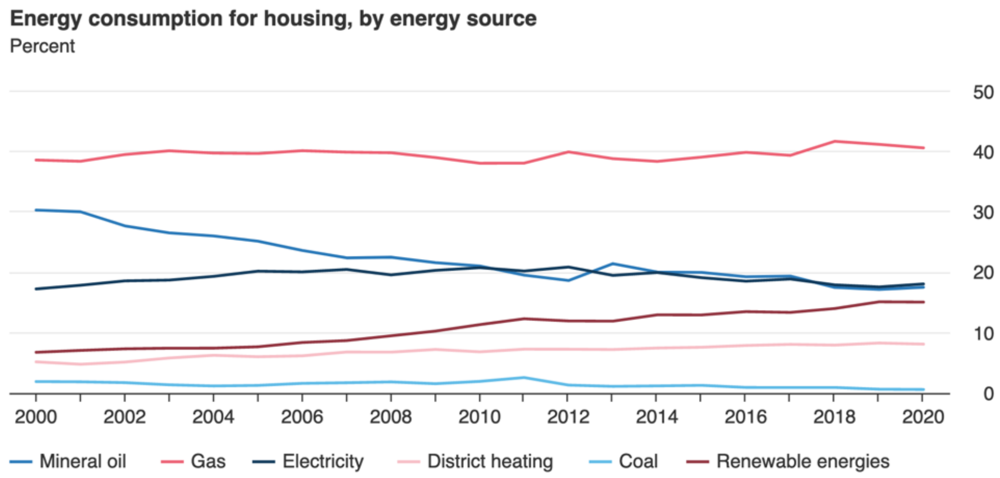
Table 5 - Energy Mix in Germany[22]

Energy sources	2019		2020		2021		2022	
	Billion kWh	%	Billion kWh	%	Billion kWh	%	Billion kWh	%
Gross electricity production, total	602.3	100	568,1	100	581.8	100	571.3	100
Lignite	114.0	18.7	91.7	16.0	110.1	18.8	116.2	20.1
Hard coal	57.5	9.5	42.8	7.4	54.6	9.3	64.4	11.2
Nuclear energy	75.1	12.3	64.4	11.2	69.1	11.8	34.7	6.0
Natural gas	89.9	14.8	94.7	16.5	90.3	15.4	79.8	13.8
Mineral oil products	4.8	0.8	4.7	0.8	4.6	0.8	4.4	0.8
Renewable energy sources	241.6	39.7	251.1	43.8	233.9	39.8	254.0	44.0
Wind power	125.9	20.7	132.1	23.0	114.7	19.5	125.3	21.7
Water power[3]	20.1	3.3	18.7	3.3	19.7	3.4	17.5	3.0
Biomass energy	44.3	7.3	45.1	7.8	44.3	7.5	44.6	7.7
Photovoltaic energy	45.2	7.4	49.5	8.6	49.3	8.4	60.8	10.5
Household waste[4]	5.8	1.0	5.8	1.0	5.8	1.0	5.6	1.0
Geothermal	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0
Other energy sources	25.4	4.2	24.8	4.3	24.5	4.2	23.8	4.1

19 (rmt/ar, 2023)
20 (Alkousaa, 2023)
21 (fek/dpa, 2023)
22 (Destatis, 2022)

Within housing itself, certain processes such as heating are not subject to the country energy production mix, as they do not run on electricity (such as gas heating). Although it is important to understand the electricity production landscape in Germany, the following chart provides a 'Micro' perspective on the energy use within residential housing.

Graph 1 - Energy Sources for Housing in Germany[23]

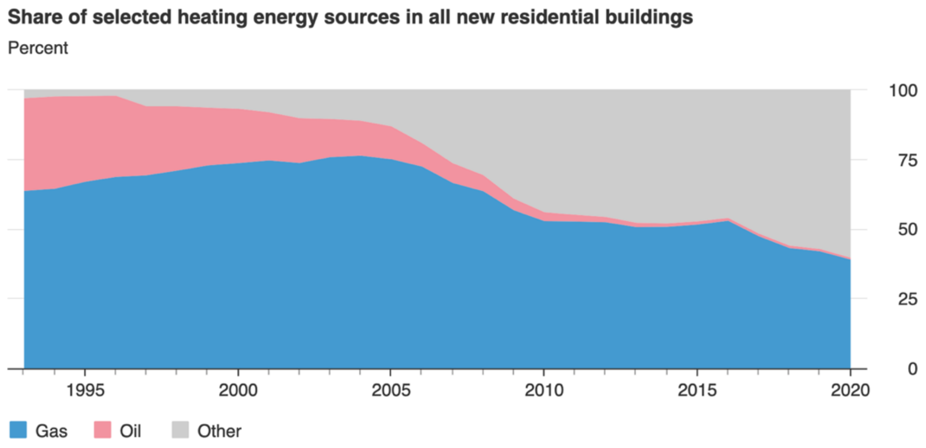


The electricity consumption has been reduced over the last two decades, as household appliances become more efficient, and certain specific regulations (such as a progressive ban on low-efficiency light bulbs in 2009[24,25]) advanced. This has been supported by an increase in the percentage of renewable energies.

Gas has been relatively stable, as room and water heating are still largely gas-driven in many households, as the chart below shows;

[23] (Destatis, 2022)
[24] (Glühbirne)
[25] (Maaß, 2023)

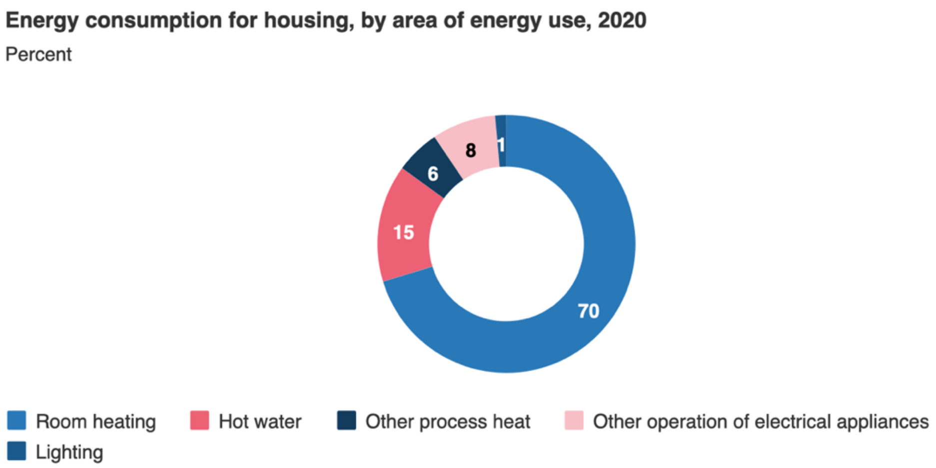
Graph 2 - Heating Sources in new residential buildings in Germany, 1993-2020[26]



Although gas is still a core heating method, positive development is the increased presence of renewable heating sources, namely heating pumps which rely on geothermal and environmental energy. This technology was present in more than 50.5% of residential buildings constructed in 2020.

The importance of transitioning heating towards more renewable and efficient methods becomes clear when observing the chart below. 85% of housing energy consumption is tied to room and water heating. This is largely the result of German geography, which experiences cold winters (especially in the south), and often faces cooler spring and autumn seasons with high precipitation.[27]

Chart 1 - Energy consumption for housing, by use[28]



[26] (Destatis, 2021)
[27] (Climate Data, 2023)
[28] (Destatis, 2022)

One should note that cooling (air conditioning) is not very common in Germany. As the summers seldom experience uncomfortably high temperatures (and humidity is low), investing in air conditioning is considered prohibitively expensive (initial investment and operating costs) for its limited utility.[29]

[29] (Lagerquist, 2022)

German Residential Efficiency Ratings

Current Standards

There exist two different energy performance certificates for residential real estate in Germany. The building owner must apply for a certificate whenever they wish to rent out, lease out, or sell the building or an apartment within. The following principles outline which certificate the building owner can opt for;

No Certificate required	– Buildings with less than $50m^2$ usable surface area – Protected historical buildings – Not regularly heated or cooled buildings
Can **choose** between **Energy Usage Certificate** (Energieverbrauchs-ausweis) and **Energy Requirement Certificate**	– Building has more than at least 5 apartments – Built after 1977 – Built before 1977 and has undergone efficiency retrofitting since
Must apply for an **Energy Requirement Certificate** (Energiebedarfs-ausweis)	– Building is separated into less than 5 apartments – Built before 1977 but has NOT undergone efficiency retrofitting since

Energieverbrauchsausweis (*Energy Usage Certificate)*[30]

This certificate is based upon the actual historical energy usage of a building or apartment. Compared to the Energy Requirement Certificate, it is easier and cheaper to have developed, given its historic-data based nature. It is valid for 10 years. The certificate takes the following factors into account:

- Energy usage for room and water heating in the previous 3 years
- Sources of energy used (renewables, gas, etc.)
- Local climate factors (GTZ)

The local climate factors are taken into account to ensure that the results are meaningful and comparable. The consumption data for individual years are adjusted to the fluctuating climate. Namely, energy usage data is corrected to control for

[30] (Effizienz Haus, 2022)

periods that were colder than usual. Experts refer to this as weather adjustment.[31] A detailed discussion of this control (*Gradtagszahl*, GTZ) can be found in the Appendix.

There exist two major inputs in the Energy Usage Certificate:

1. Final energy consumption

Measured as kWh/m^2a ; kilowatt hours per meter squared per year.

This represents the actual amount of energy directly utilized for room and water heating. It accounts for all energy lost in the heating process, such as from the water boiler itself or the building's walls. The value allows for a direct comparison of spatial energy intensity amongst different residential homes/apartments, and enables the calculation of the energy cost through the multiplication of the fuel price in kilowatt hours.

2. Primary energy consumption

This factor relates to the energy intensity to extract the fuels used in heating. It thus symbolizes the environmental balance of a raw material in the energy consumption certificate. It expresses itself as a factor which is multiplied by the previously calculated final energy consumption.

The factors are set by the Building Energy Law established in 2021, and are as follows:[32]

Category	Energy Source for Heating	Primary energy factors Non-renewable share
Fossil Fuels	Heating oil	1.1
	Petroleum	1.1
	Liquified petroleum gas	1.1
	Stone coal (anthracite)	1.1
	Brown coal (lignite)	1.2
Biogenic Fuels	Bio Gas	1.1
	Bio Oil	1.1
	Wood	0.2
Electricity	Grid-sourced	1.8
	Produced near building (from Solar or Wind)	0.0
	Displacement electricity mix for cogeneration (heat and power)	2.8

[31] (Rosenkranz, 2022)
[32] (German Federal Ministry of Justice, 2021)

Category	Energy Source for Heating	Primary energy factors Non-renewable share
Heat, Cooling	Geothermal energy, solar thermal energy, ambient heat	0.0
	Earth cold, ambient cold	0.0
	Waste heat	0.0
	Heat generated by cogeneration which is integrated in building or close to building	see DIN V 18599-9: 2018-09 Section 5.2.5 or DIN V 18599-9: 2018-09 Section 5.3.5.1
Municipal Waste		0,0

For example, a building which has a final energy consumption of 100 kWh/m²a, and heats via grid-based electricity, its resulting energy consumption is 180 kWh/m²a (100 * 1.8).

The final energy consumption then provides us with a scale of resulting Energy efficiency classes; [33]

Energy Efficiency Class	Final Energy Consumption [Kilowatt hours per meter squared per year]
A+	≤ 30
A	≤ 50
B	≤ 75
C	≤ 100
D	≤ 130
E	≤ 160
F	≤ 200
G	≤ 250
H	> 250

Energiebedarfsausweis (Energy Demand Certificate)

Unlike the previous historic usage-based certificate, the energy requirement certificate aims at providing absolute transparency by establishing the efficiency of a house based on structural features of the building. This certificate can only be produced by authorized specialists, who are recorded in a federal database.[34] Such

[33] (German Federal Ministry of Justice, 2021)
[34] (German Energy Agency (DENA), 2020)

specialists are architects, energy advisors, construction engineers, internal architects, chimney sweeps, and technicians with the relevant training.

Unlike the Usage Certificate, such a Demand Certificate is more expensive (400-650€), which is tied to the extensive data that must be gathered, calculations run, all handled by a specialist.[35]

The reasoning for the Demand Certificate is to provide an unbiased picture of a building's efficiency. As mentioned beforehand, previous owner/renter behavior can influence the heating information in a Usage Certificate, as can temporary vacancy (within the three-year evaluation period).

The evaluation of energy efficiency (as before, in kWh/m^{2}a) and the resulting energy efficiency class (A+ - H) is based on an engineering-based evaluation of numerous factors. The full calculation method cannot be reproduced here, the method's description requiring multiple hundred page handbooks.[36] The factors and evaluation process can however be summarized as:

Factors in Calculation[37]

Factor	Information
Documents about the building	– Planning documents for the building: floor plans, building description, details of the living space, details of the thermal insulation measures carried out, energy consumption data and chimney sweep records for the last three years – Basic data on the building: number of apartments, actual heated living space, adjacent neighboring buildings, etc. – Information on (possible) renovation measures previously carried out
Exterior data collection	– Exterior tour (facade, insulation, condition, etc.) – Windows (type, condition, insulation etc.) – Roller shutter boxes – Roof (pitched or flat roof, condition of roofing, etc.)
Data recording inside	– Attic (heated or unheated?) – Apartment – Windows (type of glazing, year of construction, material, etc.) – Ground (basement) – System technology in the living area (heating elements or hot water production in the living area, heat output of the

35 (German Energy Agency (DENA), 2021)
36 (German Energy Agency, 2021)
37 (Energie Experten, 2022)

	system, regulation of heat output, decentralized heat generator, etc.).
Data acquisition heating system	– Information on heat generators (number, location, energy source, mode of operation, etc.) – Data on storage tanks (if any; number, year of construction, location, mode of operation, type of heating, etc.) – Thermal insulation of piping – Water heating system – Solar system (if available) – Basis for modernization recommendations regarding installed technical equipment
Data recording ventilation system	– Type? Exhaust air system, supply and exhaust air system (decentralized), supply and exhaust air system (centralized) – Ventilated rooms – Humidification available, heat recovery rate % and system air change rate – Continuous operation, time-controlled operation or demand-controlled operation (pushbutton)

Process of Building Evaluation[38]

For the energy certificate creation, the determination of the final energy demand for room and water heating is done in two steps:

1. Building envelope surface

The amount of heat required for the building to reach the standardized room temperature in winter (19 °C or 20 °C, depending on the calculation method) is determined. This room heating demand together with the hot water demand results in the heat quantity to be provided by technical installation.

There are numerous factors affecting the calculation of this energy requirement (see above), including building density, thermal envelope area (surface separating heated building areas from ambient temperature), quality of construction parts/materials, net room volume (air volume), heat loss sources, and more.

The goal of this step is to establish an engineering-based evaluation of the energy requirements the building has.

2. Installed technical heating equipment

In this second step, the energy losses that occur during the generation, storage, and distribution of the corresponding amount of heat.

[38] (German Energy Agency, 2021, S. 10)

This step ensures that equipment inefficiencies are accounted for, and the final energy requirement of the building resembles the true operating requirement for heating.

German Buildings Energy Act (*Gebäudeenergiegesetz*, GEG) 2020[39] [40]

In November 2020 the Buildings Energy Act (GEG) came to replace various preceding regulations and laws on the efficiency and energy consumption of buildings in Germany. An outline of how this final form was reached can be found in the following section, however its ramifications are of interest here.

The GEG creates a uniform legal basis for the implementation and planning of new constructions and renovation measures. It sets forth requirements for the energy efficiency of buildings and obliges the use of renewable energies in new buildings.

The GEG is enforced in all new and existing buildings which are heated or cooled. This includes residential buildings, but also extends to public and non-residential buildings. Few and specific exceptions exist, such as greenhouses, stables, tents, religious, buildings, underground buildings, and others.

GEG - Regulations for New Constructions

All new buildings are planned and constructed as 'Low Energy Buildings'. Architects and engineers employ software which provides them with guidelines (referred to as the 'reference building') regarding insulation and energy efficiency for the blueprints they input into the software.

The regulations for new constructions are:

- Annual Primary Energy Requirement: the primary energy requirement may not exceed 75% of the primary energy use of the reference building. Thus, architects/engineers must make the power sources of the actual building more efficient than the software model.
- Heat Protection: the blueprints must ensure adequate heat protection in the summer months, which is ensured by the software.

[39] (Deutsche Fensterbau, 2021)
[40] (German Federal Ministry of the Interior and Community, 2023)

- Density and Insulation: The building envelope must be closed and sealed to avoid heat loss. However, windows must allow for a minimum airflow to avoid the formation of mold.
- Mandatory Share of Renewable Energies
  Depending on the heating source being installed in a new building, a certain percentage of the energy must stem from renewable sources.

GEG - Regulations for Renovations and Modernizations

The insulation level of the building's external envelope is defined by the U-value; the thermal transmittance coefficient. It is calculated as $W/(m^2 * K)$ (Watt per meter squared times Kelvin) and represents the rate of transfer of heat through matter. The maximum U-values for various aspects of the building envelope are:[41]

Building Part	Maximum U-value
Exterior wall (ground & unheated rooms)	0.3
Exterior wall (outside air)	0.24
Roof and ceiling of top floor	0.24
Windows	1.3
Roof Windows	1.4
Basement walls	0.3
External doors	1.8

Beyond this, old heating boilers need to be replaced if they are 30 years old and have a heating capacity of 4 – 400 kW.

General GEG Requirements

Beyond the measures listed above, there exist further requirements put forth by the GEG;

- Energy consulting in case of building ownership change or in case of certain renovations is obligatory.
- Qualified craftsmen may now also issue energy certificates
- The obligation to use renewable energies can also be fulfilled by using biogas, biomethane or biogenic liquefied gas in a condensing boiler
- The existing obligation to use renewable energies in new buildings can in future also be fulfilled by using electricity generated from renewable energies in the

[41] (Deutsche Fensterbau, 2021)

vicinity of the building. This requires at least 15% of the heating and cooling requirements to be covered.

History of German Energy Efficiency Standards[42]

The Energy Saving Act (*Energieeinsparungsgesetz*, EnEG) came into force in 1976 after the oil crisis of 1973. The crisis had made clear that a reliance on fossil fuel imports was undesirable, and that independence should be sought. Although not yet translating into any restrictions or requirements for consumers, this law empowered the German government to issue regulations to improve the energetic efficiency of buildings.
The EnEG underwent several reforms, and served as the basis of authorization for the German government until it was replaced by the 2020 GEG.

A year after introducing EnEG, the German government introduction the Heat Insulation Act (*Wärmeschutzverordnung*, WSVO). In 1977 most European countries did not yet have any regulations on building energy efficiency, wherefore the WSVO represented an important step in the energy policy. Energy import independence was the main motivator of this regulation, with environmental worries still of secondary importance.
The WSVO established minimum efficiency standards for new constructions, reconstructions, and add-ons in regards to their energetic efficiency. The stated goal was the reduction of transmission heat loss from buildings to the environment.
The WSVO was updated in 1982 and 1995, both times its efficiency standards being tightened. The WSVO was ultimately replaced in 2002 through the introduction of the EnEV.

Like the WSVO, the Heating Systems Ordinance (*Heizungsanlagenverordnung*, HeizanlV) was introduced in 1977 and replaced by the EnEV in 2002. The HeizanlV ensured that new building constructions did not install unnecessarily powerful heating systems and employed modern insulation standards. Additionally, maintenance requirements for heating units were introduced, as where thermostatic vents became mandatory.

[42] (Deutsche Fensterbau, 2020)

In 1981, the Regulation on Heating Cost Billing (*Verordnung über Heizkosten-abrechnung*, HeizkostenV) was passed. In a further push to animate consumers towards energy efficient behavior, this regulation required building owners to pass on heating costs to renters, given that the building was centrally heated and contained at least two apartments not rented by the building's owner themself.[43]
This regulation is still in place today and has proven to be highly effective.

In 2002 the German government put in place the Energy Saving Ordinance (*Eneergieeinsparverodrnung*, EnEV). This Ordinance established efficiency comparison standards for buildings, and required all newly constructed buildings to meet certain efficiency levels. Furthermore, existing buildings were required to retrofit by 2050, requiring them to likewise meet certain standards.
EnEV intended to simplify regulations by replacing the WSVO and HeizanlV within its one body. In place until 2020, it underwent several updates over the years;

- 2004: Solely the updating of certain norms
- 2007: Certain guidelines were updated to the current technical standards. Alternative energy supply systems were taken into account, and maintenance requirements for air conditioning systems was introduced.
  Most importantly, in 2007 the Energy Efficiency Certificate also became a requirement for existing buildings. This intended to motivate owners to retrofit their existing stock.
- 2009: The efficiency requirements for energy, heating, and warm water were increased. For newly constructed buildings, the heat insulation requirements were increased around 15%. Beyond this, building owners with solar panels could now include this source within the calculation of their primary energy (solar having a primary energy value of 0%).
- 2014: All energy certificates were now given the A+ - H efficiency scale. The update made it obligatory to share the energy certificate upon renting and selling and listing one's property. Additionally, states were now required to

[43] In German this is referred to as renting 'cold' vs. 'warm'. A cold rent does not include heating costs (paid separately by renter, on top of base monthly rent), whereas with a warm rent the renter pays a usually higher rent, which includes all heating and water costs.

complete random inspections for new constructions, to ensure efficiency standards were respected.

- 2016: The allowance for primary energy was reduced by 25%, resulting in stricter energy efficiency classes. Additionally, an insulation requirement for rooves or alternatively the uppermost floor was put in place. As heat rises, the upper insulation of many buildings was considered a weak spot.

Recently, in November of 2020 Germany released the German Buildings Energy Act (*Gebäudeenergiegesetz*, GEG). It intends to consolidate the various regulations and policies regarding building efficiency. As its predecessors, the law aims to reduce heating costs and drive climate protection. The law benefits builders and renovators by providing a transparent and combined regulatory overview.

Conclusion and Relevance for the United States

The investigation above has served to outline the energy landscape, housing structure, and residential energy use in Germany.

As we have seen, several factors come in to play in the Germany system. Affecting both property owners and renters, the system seldom limits property aspects outright, rather attempting to motivate change via increasing financial burden.

It would be unwise at this point to construct a theoretical American system. The German system has shown to be highly politically motivated, if even for non-environmental reasons initially. To advise a similar system in the United States would require a state-based approach, taking into account political, housing, and energy factors of each state. The geographic size, varying climates, and fluctuations in population density alone make a 'one-size' approach in the United States less feasible.

However, we have seen and discussed useful tools in the German system, which at times can be taken into account for an American system.

Firstly, the United States has a high percentage of renter occupied buildings.

Table 6 - Housing Unit Structure in the United States[44]

	2007		2009		2018	
	Owner occupied	Renter occupied	Owner occupied	Renter occupied	Owner occupied	Renter occupied
Single-family	**66,032,715**	**11,668,135**	**65,584,718**	**12,918,483**	**68,594,887**	**14,710,848**
Detached units	61,605,279	9,560,184	61,188,542	10,617,607	64,012,933	11,959,155
Attached units	4,427,436	2,107,951	4,396,176	2,300,876	4,581,954	2,751,693
Multifamily	**4,258,803**	**23,392,103**	**4,163,433**	**23,020,683**	**4,249,835**	**27,163,098**
2-to-4-unit buildings	1,770,329	7,275,600	1,681,781	7,374,780	1,650,794	7,615,659
5-to-9-unit buildings	607,522	4,615,873	597,150	4,661,338	590,975	5,068,624
10-to-19-unit buildings	487,209	4,290,786	470,329	4,397,218	481,043	4,805,393
20-to-49-unit buildings	507,643	3,124,939	501,922	3,237,116	527,498	3,868,131
50-or-more-unit buildings	886,100	4,084,905	912,251	4,350,231	999,525	5,805,291
Manufactured housing	**5,155,077**	**1,770,619**	**5,023,996**	**1,797,961**	**4,779,322**	**1,890,011**
Total	**75,515,104**	**36,862,873**	**74,843,004**	**38,773,225**	**77,624,044**	**43,763,957**

As such, it is important that the interests of landlord and renter are aligned. To ensure this, a scale-based certificate system like that seen in Germany would be useful. Such a scale provides ease of comparison for renters, whilst also rewarding landlords by enabling them to publicize the level efficiency their property boasts.

[44] (United States Census Bureau, 2018)

Secondly, the energy system in Germany has shown that energy use is not compared on a baseline across the country. Aspects of the rating system, such as the *Gradtagszahl* (GTZ) are computed on a local basis, to not punish those living in colder areas. Likewise, an American system would require this forethought. With geographies ranging from Florida to Alaska, different areas of the United States face different extremes of cold in the winter. And more so, heat in the summer. Just as baselines for winter cold should be adapted regionally, the baselines for summer heat require a similar treatment.

Thirdly, we have identified efficiency standards in regard to heat insulation in Germany. Similar standards in the United States would be wise, however again require adaptation. Namely, the southern states (the likes of Florida and Texas) are notorious for their summer heat, not their winter cold. As such, standards regarding cooling insulation should be developed instead.
This cooling notion extends to the idea of energy production efficiency. Unlike heating, which can be directly powered by gas (or coal), cooling is done by Air Conditioning (AC) units, in turn powered by electricity. Although AC is notorious for its high energy consumption, it is less concerning if the electricity is won locally by renewable energy sources.
Tracing back to the notion of the United States being geographically expansive, it is therefore again important that an energy efficiency system considers the local energy production grid when evaluating the cleanliness (or lack thereof) of its power consumption.

Bibliography

Boland, B., Levy, C., Palter, R., & Stephens, D. (2022). *Climate risk and the opportunity for real estate*. New York: McKinsey & Company.

Ritchie, H., Roser, M., & Rosado, P. (2020). *CO_2 and Greenhouse Gas Emissions.* Retrieved from OurWorldInData: https://ourworldindata.org/co2-and-greenhouse-gas-emissions

International Energy Agency. (2022). *Global Energy and Climate Model.* Online: IEA Publications. Retrieved from International Energy Agency: https://www.iea.org/reports/global-energy-and-climate-model/net-zero-emissions-by-2050-scenario-nze

United Nations. (2021). *United Nations - Climate Action*. Retrieved from The Paris Agreement: https://www.un.org/en/climatechange/paris-agreement

Skowronek, M. (2021, February 21). *Anteil der Wohnungen in Ein- und Zweifamilienhäusern gesunken (Percentage of Homes in Single and Dual Homes has sunken).* Retrieved from Die Zeit: https://www.zeit.de/wirtschaft/2021-02/einfamilienhaus-mehrfamilienhaus-wohnungen-statistisches-bundesamt-trend-ruecklaeufig

Frank, C. (2023, 2 22). *Empfehlungen für einen nachhaltigen Wohnungs- und Städtebau (Recommendations for a sustainable Living and Public Space Development).* Retrieved from Bund Deutscher Landschaftsarchitekten (Association of German Landscape Architects): https://www.bdla.de/de/nachrichten/nachrichten-de/3917-empfehlungen-fuer-einen-nachhaltigen-wohnungs-und-staedtebau

Alkousaa, R. (2023, April 15). *Reuters.* Retrieved from Atomic angst over? Germany closes last nuclear plants: https://www.reuters.com/world/europe/atomic-angst-over-germany-closes-last-nuclear-plants-2023-04-14/

fek/dpa. (2023, April 12). *FDP will endgültigen AKW-Rückbau verzögern (FDP wishes to delay final removal of nuclear reactors).* Retrieved from Spiegel: https://www.spiegel.de/politik/deutschland/atomkraftwerke-fdp-will-endgueltigen-rueckbau-verzoegern-a-b83f0d09-2faf-46ee-857f-a51b2a7f8506

Glühbirne. (n.d.). *Glühbirnen-Verbot (Lightbulb Restriction).* Retrieved from Glühbirne: https://www.gluehbirne.de/Gluehlampen-Verbot

Maaß, S. (2023, 01 27). *Bei diesen Lampen geht 2023 das Licht aus (The light turns off for these lightbulbs in 2023).* Retrieved from Welt: https://www.welt.de/wirtschaft/article243385847/EU-Verbot-Bei-diesen-Lampen-geht-2023-das-Licht-aus.html

German Federal Ministry of the Interior. (2012). *Demography Report - Federal Government Report on the Demographic Situation and Future Development of Germany.* Online: German Federal Ministry of the Interior.

rmt/ar. (2023, February 25). *Germany: Coal imports increase in 2022 amid Ukraine war.* Retrieved from Deutsche Welle: https://www.dw.com/en/germany-coal-imports-increase-in-2022-amid-ukraine-war/a-64818198

Climate Data. (2023). *Climate Data.* Retrieved from Climate Graphs & Average Temperature of Germany: https://en.climate-data.org/europe/germany-232/

Destatis. (2023, January 19). *Current Population of Germany.* Retrieved from Destatis (German Federal Statistical Office) - Population: https://www.destatis.de/EN/Themes/Society-Environment/Population/Current-Population/_node.html

Destatis. (2022, December 12). *Environmental-economic accounting - Private Households.* Retrieved from Destatis (German Gederal Statistical Office): https://www.destatis.de/EN/Themes/Society-

Environment/Environment/Environmental-Economic-Accounting/private-households/_node.html
Destatis. (2022). *Gebäude und Wohnungen - Bestand an Wohnungen und Wohngebäuden Bauabgang von Wohnungen und Wohngebäuden (Buildings and Apartments - Stock and retirements of apartments and residential buildings).* Online: Destatis (German Federal Statistical Office).
Destatis. (2022). *Gross Energy Production in Germany.* Retrieved from Destatis (German Federal Statistical Office): https://www.destatis.de/EN/Themes/Economic-Sectors-Enterprises/Energy/Production/Tables/gross-electricity-production.html
Destatis. (2023). *Housing.* Retrieved from Destatis (German Federal Statistical Office) - Society and Environment: https://www.destatis.de/EN/Themes/Society-Environment/Housing/_node.html
Destatis. (2021, October 13). *Press - 39% of the residential buildings constructed in 2020 are heated by natural gas.* Retrieved from Destatis (German Federal Statistical Office): https://www.destatis.de/EN/Press/2021/10/PE21_N060_61_44.html
Destatis. (2021, February 25). *Von Januar bis November 2020 genehmigte Wohnungen: 59 % in Mehrfamilienhäusern (From January to Febraury 2020 allowed constructions: 59% more Multi-Family Homes).* Retrieved from Destatis (German Federal Statistical Office): https://www.destatis.de/DE/Presse/Pressemitteilungen/2021/02/PD21_N015_44.html
Holm, A., Mayer, C., & Sprengrad, C. (2015). *Wirtschaftlichkeit von wärmedämmenden Maßnahmen (Economic feasibility of thermal insulation measures).* Munich: Research Institute for Thermal Insulation Munich (Forschungsinstitut für Wärmeschutz München e.V.).
Fuerst, F., McAllister, P., Nanda, A., & Wyatt, P. (2015). Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Economics*, 145-156.
Taruttis, L., & Weber, C. (2022). Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter? *Energy Economics*.
Mudgal, S., Lyons, L., Cohen, F., Lyons, R., & Fedrigo-Fazio, D. (2013). *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries.* Online: European Commission (DG Energy).
Im, J., Seo, Y., Cetin, K. S., & Singh, J. (2017). Energy efficiency in U.S. residential rental housing: Adoption rates and impact on rent. *Applied Energy*, 1021-1033.
Lagerquist, E. J. (2022, May 20). *Why is there so little A/C in Germany?* Retrieved from Ramstein Air Base: https://www.ramstein.af.mil/News/Commentaries/Display/Article/3038325/why-is-there-so-little-ac-in-germany/
Umwelt Bundesamt (Federal Ministry for the Environment). (2022, July 3). *Energiesparende Gebäude (Energy Efficient Buildings).* Retrieved from Umwelt Bundesamt (Federal Ministry for the Environment): https://www.umweltbundesamt.de/themen/klima-energie/energiesparen/energiesparende-gebaeude#gebaude-wichtig-fur-den-klimaschutz
Effizienz Haus. (2022). *Energiebedarfsausweis.* Retrieved from Effizienz Haus: https://www.effizienzhaus-online.de/energiebedarfsausweis/

Rosenkranz, A. (2022, 1 25). *Der Energieverbrauchsausweis für Wohngebäude (The energy consumption certificate for residential buildings)*. Retrieved from Heizung: https://www.heizung.de/ratgeber/diverses/der-energieverbrauchsausweis-fuer-wohngebaeude.html

Kesselheld. (n.d.). *Gradtagszahl: Gradtagstabelle, Berechnung & Definition.* Retrieved from Kesselheld: https://www.kesselheld.de/gradtagszahl/

DWD (German Meteorological Services). (n.d.). *DWD (German Meteorological Services)*. Retrieved from Gradtagzahlen/Gradtage : https://www.dwd.de/DE/leistungen/gtz_kostenfrei/gtz_kostenfrei.html

German Federal Ministry of Justice. (2021). Retrieved from Gebäudeenergiegesesetz 2021, Anlage 4: https://www.gesetze-im-internet.de/geg/anlage_4.html

German Federal Ministry of Justice. (2021). Retrieved from Gebäudeenergiegesesetz 2021, Anlage 10: https://www.gesetze-im-internet.de/geg/anlage_10.html

German Energy Agency (DENA). (2020). *Suche der Ausstellerinnen/Aussteller von Energieausweisen (Search for the issuers of energy certificates)*. Retrieved from Effizienzhaus: https://effizienzhaus.zukunft-haus.info/aussteller/suche-experten/

German Energy Agency (DENA). (2021). *Transparent energy use - Information in the energy performance certificate*. Retrieved from German Energy Agency (DENA): https://www.dena.de/en/topics-projects/energy-efficiency/buildings/consulting-and-planning/energy-performance-certificate/

German Energy Agency. (2021). *Teil 1 – Energiebedarfsausweis: Datenaufnahme Wohngebäude. (Part 1 - Energy Demand Certificate: Data Collection for Residential Buildings).* Online: German Energy Agency.

Energie Experten. (2022, 11 28). *Bedarfsausweis: Berechnung, Pflichten, Anbieter & Kosten (Demand certificate: calculation, obligations, providers & costs)*. Retrieved from Energie Experten (Energy Experts): https://www.energie-experten.org/energie-sparen/energieberatung/energieausweis/bedarfsausweis#c48924

Deutsche Fensterbau. (2020). *EnEV, WSVO und GEG – Geschichte der Energiegesetze in Deutschland (EnEV, WSVO and GEG - History of energy laws in Germany)*. Retrieved from Deutsche Fensterbau: https://www.deutsche-fensterbau.de/ratgeber-energiegesetze/

Deutsche Fensterbau. (2021). *Das GEG 2020 – Fragen und Antworten zum neuen Gebäudeenergiegesetz (The GEG 2020 - Questions and answers on the new building energy law)*. Retrieved from Deutsche Fensterbau: https://www.deutsche-fensterbau.de/ratgeber-geg/#gebaeudearte

German Federal Ministry of the Interior and Community. (2023). *The new Buildings Energy Act*. Retrieved from Buildings Energy Act (Gebäudeenergiegesetz): https://www.bmi.bund.de/EN/topics/building-housing/building/energy-efficient-construction-renovation/buildings-energy-act/buildings-energy-act-node.html

Appendix

Germany

Winter Temperature Fluctuations – GTZ

To correct for the winter fluctuations, the *Gradtagszahl* (GTZ, degree day) is employed.

Degree days (GTZ) are used to calculate the heating demand of a building during the heating period. They represent the relationship between room temperature and the outside air temperature for the heating days of a design period and are thus a tool for determining heating costs and heating fuel requirements. The period of consideration is October 1st till April 30th of the following year.[45] This period is expanded on a regional basis if preceding or following months measure an average ambient temperature of 15 degrees Celsius. The period is however not reduced, even if months within the consideration period (October-April) lie above this average temperature.

Degree-day values are measured in Kelvin, so that they have the same unit as temperature in Germany (degrees Celsius). They are calculated for various time periods (annual, monthly, daily, a heating period) and for various locations (city, regional, state). In each case, there are values for the long-term ambient average temperature and the current weather (in time meteorological measurement).

In Germany, two reference values are used for ambient temperature and internal heating limit; 20 degrees Celsius and 15 degrees Celsius, respectively. These values were established by the German Association of Engineers (VDI) guideline 2067.[46]

The references in Germany are represented in the following format: $GTZ_{20/15}$. Other countries may use other benchmarks, such as 20/12 in Switzerland, Austria, and Liechtenstein (a lower internal heating limit).

Degree days are only measured when the ambient temperature falls below the 15 degrees Celsius internal heating limit. The GTZ value for that day is then the difference between the day's average ambient temperature and the 20 degrees Celsius benchmark for room temperatures.

[45] (Kesselheld)
[46] (DWD (German Meteorological Services))

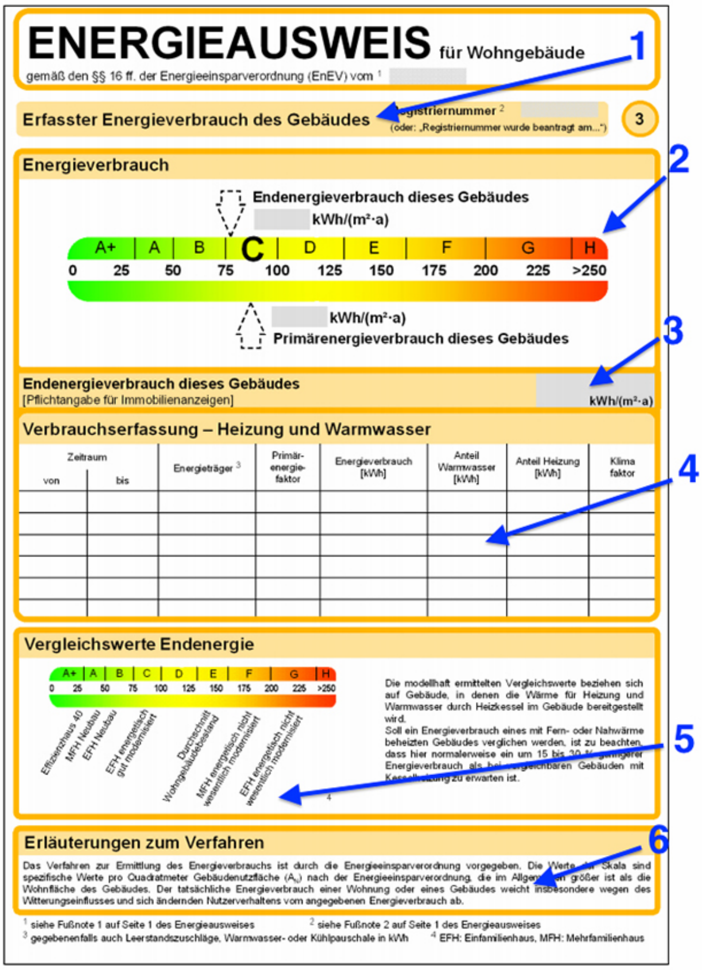
This method can also be illustrated via the following formula from the VDI 2067 guideline:

$$G_{t20/15} = \sum_{1}^{z} (t_i - t_a)$$

Whereby:

- $G_{t20/15}$: the degree day (GTZ) with a t_i of 20 and a t_a of 15 (degrees Celsius)
- z : number of heating days within the consideration period
- t_i : assumed internal room temperature, in Germany 20 degrees Celsius
- t_a: average ambient temperature of the particular heating day

Figure 1 - German Energy Certificate for Residential Buildings[47]



[47] (Energie Experten, 2022)

1 – Registered energy consumption of the building

2 – Scale indicating energy efficiency class, based in final and primary energy use

3 – Total energy consumption of the building

4 – Historic usage data for room and water heating

5 – Comparison slider for energy efficiency

6 – Explanation of measurement process