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Data-driven decision making for approaching the near-zero energy building vision in construction

submitted by

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Statement of Authorship

I hereby declare that I am the sole author of this thesis and that I have not used any sources other than those listed in the bibliography and identified as references. This work has not been submitted to any other examination authority.

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Abstract

Powered by the European Directives on Building Energy all European countries are ought to find solutions to lower the consumption of non-renewable resources and to lower the dependence of the Union on energy imports.

By using near-zero energy concepts and implementing renewable energy in buildings, we are able to better understand the building's behaviour. Consequently, we can create a more universal application for tenants. In addition, we reduce the demand for primary energy (heating, domestic hot water and electric energy consumption) by analysing renewable sources. This will get us closer to the vision of nearly-zero energy consumption as a basic requirement for building construction.

Keywords near-zero energy buildings, energy performance, semantic models.

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Chapter 1

Introduction

making this work possible, for support and guidance.

Near-zero energy buildings are not only a new trend, but a necessity, if we take into account the environmental issues that humanity is currently facing. The decrease of the consumed energy is an urgently needed measure. By lowering the energy used in buildings for heating, cooling and appliances, we contribute to the minimisation of the effects of climate change. Near-zero energy buildings are designed to consume as less energy as possible by not compromising the thermal and visual comfort of the building occupants.

This thesis was structured as follows. First we motivated and introduced the topic of energy efficient buildings. Then we summarized the current standards and certification schemes for energy efficient buildings. We described the software frameworks and tools available in the field of energy awareness and energy prediction.

TODO: add a short description of the rest of the chapters after their topic is fixed

1.1 Motivation

Driven by the increasing concerns regarding climate change the European Union developed a legal framework for energy efficiency measures, in form of directives, in order to lower the impact on our environment.

According to the statistics published in the European Energy Directives[1] almost 50% of the European Union's final energy consumption is used for heating and cooling, of which 80% is used for residential and non-residential buildings. This makes the building sector an important energy consumer. These numbers motivate the European Union to refurbish the European building stock in order to achieve higher energy efficiency values. The current European Directives encourages nearly zero-energy consumption as a future basic requirement for construction.[73] It has been proven, e.g. with the PassivHaus standard, which we will present in detail later in this chapter, that buildings can use much less energy.

[1] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 on energy efficiency

This thesis and more specific the resulting application aims at helping building occupants and building owners, which are normally no building experts, in properly classifying their dwellings[2] based on the available data of their building. Furthermore, they receive recommendations on how to elevate their dwellings for a higher certification level.

The ultimate goal of this thesis is to create data-driven models, which help owners and future tenants to control their buildings. To reach this state, first of all buildings must be investigated paying special attention to heating (heating and domestic hot water - DHW), electric energy consumption and possible solar energy gains (e.g. gathered from photovoltaic solar panels (PV) or passive solar systems). All these considerations have significant influence in three main aspects:

- Limitation of environmental impact
- Becoming more self-sufficient
- Awakening the inhabitants awareness in terms of energy consumption

The above considerations have an impact on each other and should be treated holistically. This research aims at finding a solution for these challenging problems.

In this thesis we focus on building renovations. According to the European Directive, each Member State has to renovate 3% of their building stock yearly, with focus on the public sector. The ultimate goal by 2050 is to renew the building stock into nearly zero-energy buildings.

TODO: reformulate the above aim, in case the practical part will have a completely different goal

TODO: add key questions

TODO: add argumentation flow

1.2 Energy Efficiency

The term *energy efficiency* stands for "using less energy inputs while maintaining an equivalent level of economic activity or service"[25]. Put in other words, efficiency is the ratio between a costly input and the desired outcome. In the case of buildings, desired outcomes may be:

- thermal comfort
- adequate light levels
- air quality

and costly inputs may be:

- the amount of gas used by boilers

[2] a house, a flat or other place of residence

- the amount of electricity used for lights
- the amount of electricity used for mechanical ventilation systems

The higher the energy efficiency, the least of the costly inputs need to be used.

On the other hand, the term *energy saving* is "a broader concept that also includes consumption reduction through behaviour change or decreased economic activity"[25]. Actually the two terms are often used interchangeably.

1.2.1 Legal Framework

The European Union is concerned about the consequences of climate change on the Union's economy, so it empowers its Member States to improve the energy efficiency (especially in buildings) and to lower greenhouse gas emissions (especially in transportation). In this regard the European Parliament and the European Council published in the past several years the *European Directives* and the accompanying documents as a legal framework for energy efficiency measures. For the building sector, the focus changed from energy performance of buildings in 2010[3] to energy efficiency of buildings in 2012[4] and 2018[5]. With the 2018 Energy Efficiency Directive[73], which is the up-to-date Directive at the time of writing, a set of measures and goals were published in view of the years 2030 and 2050. The requirements are to use energy more efficiently at all stages of the energy chain (energy generation, transmission, distribution and end-use consumption). Additionally each Member State has to develop its own methods for building energy assessment, which will lead to building energy certificates.

With this Directives the EU aligns to the global vision of reducing the effects on climate change. The Paris Agreement[6] is an effort of the United Nations[7] to motivate all nations into a common goal, that of combating climate change and adapt to its effects. A research by the Regulatory Assistance Project[66] shows that without ambitious energy efficiency targets, the EU will have difficulties in meeting the goals set in the Paris Agreement.

The novelty in the latest EU Directive published in 2018 is the *Smart Readiness Indicator*. It represents a new dimension in the building energy efficiency sector. The Smart Readiness Indicator (SRI) is a optional policy instrument with the aim of raising more awareness about the benefits of smart building technologies. Smart Readiness is an indicator, that "should be used to measure the capacity of a building to use information and communication technologies and electronic systems to adapt the operation of buildings to the need of the occupants and the grid and to improve the energy efficiency and the overall performance"[73]. According to the EU Energy Directives, by mid 2020

[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

[4] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

[5] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU and Directive 2012/27/EU

[6] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[7] The United Nations is an intergovernmental organization for maintaining international peace and security, https://www.un.org

an optional scheme for rating the smart readiness of buildings will be published. This scheme will include the definition of the smart readiness indicator and a methodology for calculating this indicator. This methodology will take into account technical features like smart meters, building automation and control systems.[73] The details to proposed methodologies are presented in section 2.1.1

The technologies existing inside a house should be able to communicate with each other. If this is not the case, then an effort should be done to improve this communication, instead of adding more and more gadgets.

Additional goals of the European Union are to become a competitive low carbon economy as well as an autonomous energy provider. The ambitious energy savings are set at 20% by 2020 and 32.5% by 2030. Fore example, every 1% energy saved reduces the gas imports by 2.6.%. Energy savings would slowly lead to the vision of an European energy autonomy.[26].

The European building stock is quite old (around 80% of buildings in Europe are over 30 years old, of which not few are over hundred of years old). The big boom in construction was between the years 1962 and 1990, when building energy regulations were limited. Non-renewable sources are widely used for heating throughout the European Union (gas and oil in North and West Europe, and coal in Central and Eastern Europe where district heating is the most common heating system). Renewable energy sources (solar heat, biomass, geothermal and wastes) have a share of 21%, 12% and 9% in total final consumption in Central and Eastern, South and North and West regions, respectively.[21]

But the progress of renewing the building stock inside the EU is still slow: only 1.4% of all buildings are renovated each year, 64% of space heaters are still inefficient and 44% of windows are still single glazed. The energy efficiency already improved in the area of technical equipments (e.g. heat pumps, condensing boilers and cooling supply technologies) but further research and innovation is needed for new construction materials and methods with a potential for energy savings.[27]

The slow pace of renovations are due to different reasons. Some identified barriers for the European Union's energy efficiency plan [25][45] are:

- *the split incentives*: who bears the cost for the renovations? The tenant receives a higher living standard and the owner might sell the dwelling for a better price. But who pays and in which percentage? The problem arises when owners believe that renovations are not worth the investment since they will not be the ones enjoying the benefits, but the tenants are. And the tenants refuse to invest as well since their renting contracts are usually to short for renovation investments to pay off.

- *the missing qualified manpower*: the energy efficiency strategies require specially trained craftsman for this kind of goals.

- *the lack of awareness of efficient technologies*

- *the obstacles in investment*: e.g. the high prices for cutting-edge technologies.

To overcome some of this barriers a better evaluation, monitoring and verification is needed. Furthermore, higher investments and also policy innovation is required.

Improvements in buildings can save money for the building occupants. The households in the European Union spend on average 6.4% of their income on home-related energy use, about two thirds for heating and one-third for other purposes. In 2012 almost 11% of the population of the EU were unable to keep their homes adequately warm. This is also known as fuel poverty, which can lead to anxiety and depression[60]. Energy efficiency should be a mandatory requirement and the energy efficiency level should be made visible.

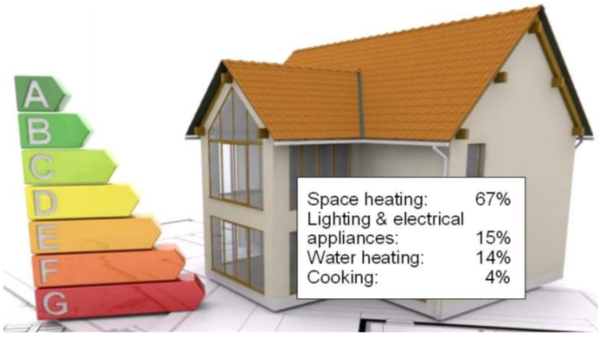

Figure 1.1: Household energy consumption[8]

The European Union offers funds which can be accessed for energy efficiency improvements in residential buildings. The *European Local ENergy Assistance* (ELENA)[9] offers support for the implementation of energy efficiency measures and for the integration of renewable energy sources and intelligent systems in buildings. The *Smart Finance for Smart Buildings* (SFSB)[10] initiative tries to make investments in energy-efficiency in buildings more attractive for private investors.

The non-renewable sources are not only of a finite amount, but for example in the case of fossil fuels, they also emit toxic gases while they are burned in order to generate heating. The toxic gases have a crucial influence on the health of the inhabitants and on the surrounding natural environment.

Since transportation has the second largest potential[25], after buildings, a further goal is to enable a decrease of greenhouse gas emissions. The aim is at 40% by 2030 (in comparison to the 1990 emissions) and the ambitious target of 80%-95% by 2050 [73]. The usage of electric vehicles contribute to the greenhouse gas emissions and are quite popular nowadays. Some parking lots offer free charging stations for e-cars in order to encourage their usage [70]. The e-charging facilities are a requirement of the European Union for renovated parking lots [73]. In the future, electric cars might be viewed as appliances of buildings (e.g. family houses, office buildings), in which case, this cars have to be taken into account in the energy performance of buildings.

Passive solutions like street vegetation, green roofs and walls that provide insulation are also encouraged by the European Union[73].

[8] Source: Odyssee indicators, www.buildup.eu, the image was taken from [25]

[9] ELENA https://www.eib.org/en/products/advising/elena/index.htm

[10] https://ec.europa.eu/energy/sites/ener/files/documents/1_en_annexe_autre_acte_part1_v9.pdf

1.2.2 Building Standards

A *standard* is a set of guidelines and criteria against which a product can be rated. Some standards are nation wide, e.g. DIN in Germany, ÖNORM in Austria, some are international e.g. EN in the European Union and some standards are worldwide standards - the ISO standards. The International Standards Organization (ISO) manages standards and certifications worldwide that frequently become law or form the basis of industry norms. ISO defines a standard as: "a document, established by consensus, approved by a recognized body that provides for common and repeated use as rules, guidelines, or characteristics for activities or their results."[80] International standards are the common language of business or industrial partners[11]. Common standards related to buildings are settled by organizations such as ANSI[12], ASTM[13], or ASHRAE[14].

In the building construction, the industry assessment standards are relevant for energy performance certifications. There are different standards in use today, the most important ones are presented next. They differ in their approach but also in their scope.

The *PassivHaus* standard was developed by the PassivHaus Institute[15], a German independent organisation in the mid 1990s. The PassivHaus standard is currently in use also in Austria[16], in the UK [17], as well as in the US[18]. The goal of this institute is to establish an effective low-energy building standard. In order for a building to be accredited with the PassivHaus standard, the PassiveHause Institute validates the building's assessments for compliance. The PassiveHaus Institute developed a software package called PassivHaus Planning Package, which can be used by the paying partners, for which the Institute offers special training.[63]

The design criteria of the PassivHaus standard are[11],[77],[47]:

- The energy needed to heat the building is less than 15 kWh/m^2 per year.
- Airtightness is less than 0.6 air changes/hour, meaning how much air leaks through the fabric of the building.
- Primary energy, the energy that is needed to power all of the activities within the building (heating, hot water, lighting, cooking, appliances, active cooling) has to be at most 120 kWh/m^2 per year.
- Thermal comfort must be met for all living areas during winter as well as in summer. The frequency of overheating, where temperature inside the house rises over 25°C in summer, must be less than 10% of the hours in a year.

[11] https://www.austrian-standards.at/en/products-services/ordering-international-standards/

[12] The American National Standards Institute (ANSI) is a private non-profit organization that oversees the development of standards in the United States.

[13] ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes technical standards.

[14] The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an American professional association aiming at improving heating, ventilation, air conditioning and refrigeration systems design and construction.

[15] https://passivehouse.com

[16] https://passivhaus-austria.org

[17] https://passivhaustrust.org.uk

[18] https://www.phius.org

The PassivHaus standard demands energy efficient building elements, e.g. in some climates the usage of highly efficient windows with triple-pane insulated glazing with air-seals and specially developed thermal break window frames [83]. The coated glass helps reflect heat back inside the house in winter (see figure 1.3). The windows are placed in such a way that it keeps optimum heat levels, e.g. the largest windows are placed towards south to help keep the house warm or placed under a deck so that the winter sun, lower in the sky, penetrates the house directly, but the summer sun, which is higher in the sky is shaded by the deck and keeps the house cool (see figure 1.2).[35]

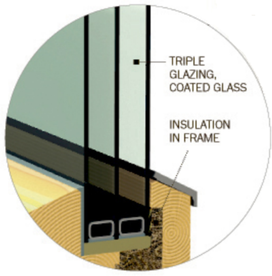

Figure 1.2: Windows in the PassivHaus Standard[19]

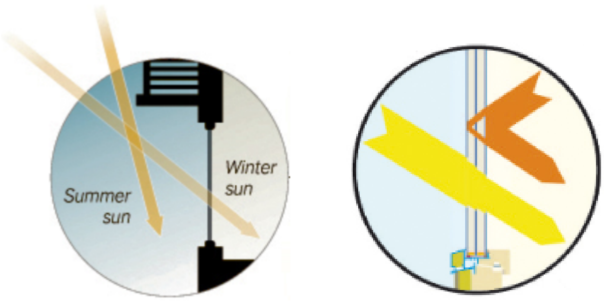

Figure 1.3: Sunlight and heat management of windows in the PassivHaus standard[20]

The indoor temperature of a PassivHaus is evenly distributed. The surface temperature is similar to air temperature (see figure 1.4). A PassivHaus building is airtight and dry in comparison to a typical building of the same climate which feels draughty and might create condensation (see figure 1.5).

PassivHaus shows a successful design for low-energy buildings.[63] The costs of applying the PassivHaus concept are higher than those of conventional building procedures (due to the energy performance efforts e.g. the usage of high-quality materials in order to comply with the PassivHaus design concepts, or certification costs), but in the long run the investment is returnable due to the low energy consumption of PassivHaus buildings. PassivHaus concepts aim for high energy performance but not necessarily for high technology.

[19]Source: [35]
[20]Sources: [35] and [47]

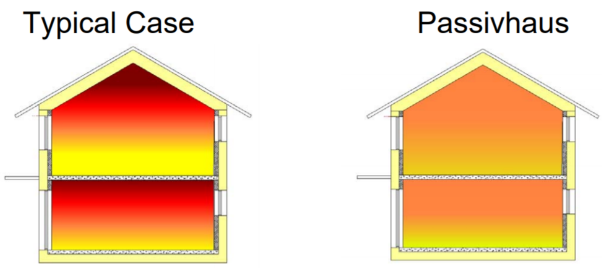

Figure 1.4: PassivHaus vs. typical building's indoor temperature distribution [11]

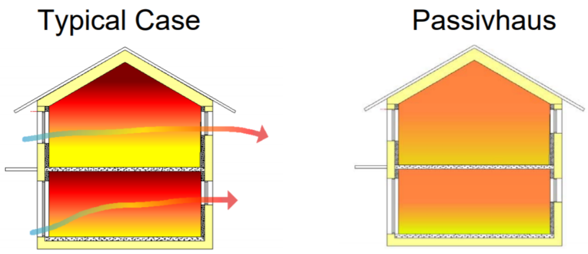

Figure 1.5: PassivHaus vs. typical building's air movement [11]

The Association for Environment Conscious Building (AECB), who developed a sustainable building standard in the UK, choose to adopt the PassivHaus standard already in 2005 since it aligns with the AECB's strategic approach[14], [30]:

- enables the selection of the best quality building fabrics
- energy performance is approached holistically (including lighting and appliances)
- the targeted values for energy consumption and emission savings are clearly appointed and measured

Standard Assessment Procedure (SAP) is a governmental initiative in the UK for measuring the energy rating of residential dwellings. It calculates the annual energy costs for space and water heating, for lightning, and it also calculates the CO_2 emissions. SAP is the backbone for Energy Performance Certificates in the UK. It is compliant with the European Directive for Energy Performance of Buildings. There are different versions of this methods SAP 2012[21], SAP 2016[22] and SAP10[23]. At the time of writing the official version is 2012, the later ones are consultation versions and not yet official. The drawback of earlier SAP standards was, that it did not provide accurate calculations for low-energy buildings as it is debated in [14].

Compared to the PassivHaus standard, which was especially developed for low-energy buildings, the SAP standard tries to catch up in their methodology to better

[21]https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf, maintained by Building Research Establishment(BRE)

[22]https://www.bregroup.com/sap/standard-assessment-procedure-sap-2016/

[23]https://files.bregroup.com/SAP/SAP-10.0_24-07-2018.pdf, issued 2018

assess the low-energy buildings. In the SAP recommendation the dwellings are rated according to their performance e.g. 1-20 points corresponds to the lowest label "G", were as 92 points and above corresponds to the highest label, that is "A". The calculations in the SAP methodology are based on BREDEM (the Building Research Establishment Domestic Energy Model). Among other characteristics, the BREDEM model allows the user to take account of the heating season length and of building location inside the UK. The SAP methodology was developed to be used as a worksheet. But there are several software tools that take SAP as calculation methodology e.g. FSAP[24] or Elmhurst's Design SAP Energy Software[25].

The *ASHRAE Standards* are a set of standards developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in the US. Their goal is to offer guidelines for indoor-environment-control technologies for example in areas such as refrigerant emission reduction, air quality, thermal comfort and building energy efficiency. The ASHRAE organisation works closely with the US government and research institutes to develop standards for the building industry. These standards are currently in use worldwide. Some ASHRAE standards that are closely related to the energy performance of buildings are[26]:

- ASHRAE Standard 55 - the Thermal Environmental Conditions for Human Occupancy Standard, is used worldwide in the industry, but also in research papers, to evaluate comfort of the building occupants. The ASHRAE Standars 55 comprises two evaluation methods, one is a survey conducted on the occupants and the other method is executing technical measurements with the aim to evaluate the buildings comfort. Some more details are presented in teh next paragraphs.
- ASHRAE Standard 62 - Ventilation for Acceptable Indoor Air Quality
- ASHRAE Standard 90.1 - the Energy Standard for Buildings except Low-Rise Buildings
- ASHRAE Standard 90.2 - Energy-Efficient Design of Low-Rise Residential Buildings
- ASHRAE Standard 100 - Energy Efficiency in Existing Buildings, aims at providing criteria which will lead to energy performance of existing buildings. This standard takes into account the different climate zones in the US
- ASHRAE Standard 189.1 - Standard for the Design of High-Performance Green Buildings

A special set of building standards, the thermal comfort standards, are currently in use for evaluating the thermal comfort of buildings. Since the indoor temperature control (e.g. air conditioning) contributes to the carbon fingerprint of a building, the topic of the thermal comfort is of a high importance in the design of low-energy buildings.[58]

[24] https://www.stroma.com/software/fsap

[25] https://www.elmhurstenergy.co.uk/software/sap-energy-software

[26] A list of all ASHRAE standards https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards

These standards take into account the energy needed to ensure a proper comfort level for the inhabitants.

The thermal comfort standards are based primarily on mathematical models. The first comfort model, which was integrated in a standard, was Fanger's static model. It was used in the standards ASHRAE 55 and ISO 7730 [4]. The Fanger's static model, also called the Predicted Mean Vote (PMV) model, was developed on the basis of laboratory studies, in a controlled environment. In consequence, this model is intended mainly for sealed air-conditioned buildings, where the windows are non-operable and the occupants interact with an artificial indoor environment. This model was found not to be suited for sealed air-conditioned buildings in hot climate zones, but it is still used in lack of a suitable model [4]. The Fanger's static model creates a relation between six primary factors: four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level). The index resulted from this model can be used to predict the average thermal sensation of a group of people in a closed space.[40]

The *Adaptive Thermal Comfort* model is a newer approach to the evaluation of thermal comfort in buildings. The adaptive comfort model, in contrast to the Fanger's model, does not directly take into account the six comfort factors, instead this factors are deducted from the outdoor temperature [40]. After a revision of ASHRAE 55 in 2004, the adaptive comfort model was introduced into this standard.

Adaptive "is generally interpreted as the ability to open a window, draw a blind, use a fan, but it also must include the usage of clothing. Changes in clothing, activity and posture and the promotion of air movement will change the conditions which people find comfortable."[59] The adaptive approach to thermal comfort is based on the natural tendency of people to adapt to changing conditions in their environment.[40] An adaptive comfort standard allows higher temperatures in summer when outdoor temperatures are high, because inhabitants are able to better adapt to that warmer environment.[40] The promoter of the adaptive approach was the European project Smart Controls and Thermal Comfort (SCATs)[27]. It aimed to reduce the energy used by air conditioning systems [57], [37]. Naturally ventilated buildings typically use about half the energy of ones which are air-conditioned. From the standpoint of low-energy buildings, a variable indoor temperature standard (e.g. adaptive thermal comfort standard) is of advantage. Whereas a constant temperature standard is against the use of natural ventilation and leads to the consumption of more energy.[59]

Currently, the ASHRAE 55 standard and the EN 1521 standard (as of 2019 called EN 16798: Energy performance of buildings - Ventilation for buildings)[28] [29] propose the Fanger's static model for mechanically heated and/or cooled buildings and the Adaptive Thermal Comfort Model for occupant controlled, naturally ventilated buildings.[4] The adaptive model is implemented differently in the two standards ASHRAE 55 and EN 15251/16798. The ASHRAE 55 standard uses the monthly mean outdoor air temperature, whereas the EN 1521/16798 standard uses the weighted running mean of

[27]https://cordis.europa.eu/project/id/JOE3970066

[28]https://www.cen.eu/news/brief-news/Pages/EN-2019-022.aspx

[29]https://shop.austrian-standards.at/action/de/public/details/664889/OENORM_EN_16798-1_2019_11_01

the outdoor air temperature. This difference makes the EN 15251/16798 more realistic [37]. The ASHRAE Standard 55, focuses on mechanically ventilated buildings (air-conditioned buildings), whereas the European Standard 1521/16798 applies to free-running buildings, that is, buildings where the occupants operate windows by themselves. In free-running buildings the outdoor temperature influences the indoor temperature. In the EN 1521/16798 standard, it is assumed that the inhabitants can freely choose their clothing, and adapt to the indoor temperature change [37].

In conclusion, the SAP method offers energy performance models, so that all kinds of buildings (from non-efficient throughout efficient ones) can be rated, whereas the PassivHaus standard offers models that aim for the best performing buildings, regarding their energy consumption. ASHRAE offers a suite of standards, covering a variety of scopes: thermal comfort of tenants, energy performance in buildings (among them also historical buildings) etc. The European Standard EN 16798, in the area of adaptive comfort models, gives parameters that need to be respected in the design of building heating, cooling, ventilation and lighting systems, in order to make them more energy efficient. This standard takes into account a year-round evaluation of the indoor thermal environment.

1.2.3 Building Rating and Certification Systems

A *certification* is a confirmation that a product meets the defined criteria of a standard. ISO defines certification as: "any activity concerned with determining directly or indirectly that relevant requirements are fulfilled"[80]. An Energy Performance Certificate might show how liveable or not is a building. A standard proposes calculation models and methodologies, whereas a certification may implement them (see Fig. 1.6).

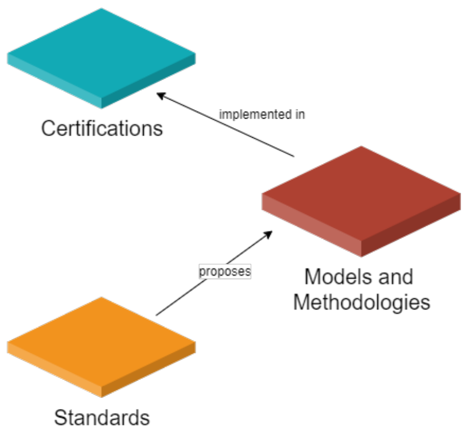

Figure 1.6: Standards vs. Certifications

Rating systems are a type of certification systems that rates or rewards relative levels of compliance or performance with specific requirements and criteria. Rating systems and certification systems are frequently used interchangeably.[80] In the building sector there is a wide variety of rating schemes: asset versus operational, whole building versus tenant ratings, “just energy” versus life cycle or sustainability ratings. This different rating types will be described in the next paragraphs.

Building Rating Systems

Building Rating systems are a type of certification systems that rates or rewards relative levels of compliance or performance with specific requirements and criteria. There are two types of assessment methods that can be distinguished based on the assessment method, operational rating and assessment rating. The two methods are not opposite, but each has it's own focus and goal.

An *operational rating*, or as the alternative name of metered energy consumption rating already states, it is a rating method that takes into account mainly the consumption data gathered from utilities. Since it relies on already consumed energy data, this type of rating can be used only for existing and operating buildings. Ideally, buildings in which the change of tenants is seldom and so the energy consumption is stable and predictable. The advantage of this type or rating is, that it documents how improvements of energy efficiency measures, including improvement on user behaviour, can change the consumption patterns. The disadvantage of the operational rating is, that it is reliable only after about two years of operation of a new building, after the building fabric, the operational building systems and the users have accommodated. Operational ratings are usually conducted periodically and are more like a "longitudinal" view of building performance. [44],[7]

An *asset rating*, or calculated/predicted energy rating, is an assessment type that calculates the energy use in relation to the attributes of a building and the systems incorporated inside a building. This type or rating is suitable on one hand, for new - still in the design stage or built but not yet operated - buildings. In this context the asset rating is useful in documenting the compliance of buildings and can provide guidelines for how much energy a building should be using under standardized conditions. On the other hand, the asset rating is used in already operating buildings, where the energy consumption pattern is quite unstable due to frequent change of tenants. In some context, this type of rating might be more useful than other rating types, e.g. for small buildings where the new occupants might have a different energy need and the rating should not be influenced by the energy use of previous tenants. The asset rating is more like a one-time snapshot of the current or the predicted building performance. [7] On large and complex buildings the asset rating assessment can be more costly than the operational rating method. This is due to the fact that asset rating relies on calculated/predictive energy models, which would be needed to be recalibrated at each re-rating of the building.[44],[7]

Some countries, like Denmark, use the asset (calculated) rating for all small buildings, old and new, but for large and complex buildings the rating of choice is the operational (measured) rating type, partly because some buildings require regular certifications and in this case the operational rating type proofed to be better suited from the financial point of view. But most countries are using the operational assessment type for large and complex buildings, and the asset (calculated) rating type for small and new buildings.[44]

The different dimensions of rating schemes makes it difficult to compare buildings for energy efficiency, but some key elements can be used as a framework to compare this rating schemes. The key elements of rating schemes identified in the report [7] are:

- type: mandatory or voluntary
- usage: for selling or renting, which might be done once every 10 years, this makes the rating scheme outdated; or for advertising a sell/rent where the rating is used as a marketing tool
- timing: if it is a regularly performed assessment, like the operational rating, or an one-time assessment like the asset rating
- disclosure: if the rating schemes and/or the rated buildings are publicly available
- assessment type:
  - the assessment method (asset or operational or both) and what are the reference values for the performance scale (absolute or relative values to similar buildings
  - the assessment dimension (what aspect of the building is assessed): life cycle assessment ratings, energy performance ratings, the smart readiness indicator
- visualisation: if the certification document is issued with enough details. Does it contain recommendation for the improvement of energy performance? Does it include predictions on future consumption?

The philosophy, the approach, and the certification method may vary across these systems, but they are all designed to reduce the overall impact on the environment and on the human health. None of the certification systems are one-size-fits all, each building project is different[80]. A building should aim for more than one certification, one for each point of view. Future research might lead to certification systems that fits all.

There are four principles that should be considered when evaluating a building rating or certification system [80]:

- Science-based, where the results and decisions must be reproducible by others using the same standard.
- Transparent, where the standards and processes for awarding the certification should be transparent and open for examination.
- Objective, where the certification body should have no personal interest in the outcome.
- Progressive, where standards should advance industry practices.

As buildings and users change over time, most certification schemes have a limited validity, typically between five and ten years. Each country has a different rating system, some examples of rating schemes are presented in section *1.2.3*.

Labelling

Some countries introduced voluntary certifications schemes, called energy labels. This are awards offered by the government for low-energy buildings. For example in Singapore, yearly the best 25% of buildings that achieve a certain energy saving goal, receive the BCA Green Mark[30] label. In the USA and partly in the EU the label EnergyStar[31] was in use that marked the low energy consumption of appliances. EnergyStar is discontinued as of 2018. The European Union intends to apply labelling frameworks for building components (e.g. windows). The reason for this is, that more than 40% of windows in the EU are still single-glazing, and another 42% are outdated uncoated double-glazing[32].[25]

Life Cycle Assessment Type Certification Systems

Life Cycle Assessment type ratings or certification systems focus on buildings as a whole, from design, to construction until demolition, while taking into account the environmental impact.

Environmental concerns are the thriving force behind the development of Life Cycle Assessment certifications systems. These certification systems are not only focusing on the energy consumption of a building, but they are concerned about the complete life cycle of a building. During the construction, renovations or re-purposing and even during the demolition of a building, not only water and energy is consumed, but also toxic emissions might be released into the atmosphere. The first UK life cycle rating system for sustainable building design was BREEAM[33] developed and certified by Building Research Establishment (BRE). Currently it is adopted also in EU countries. Worldwide they are different similar rating systems. The most well-known is Leadership in Energy and Environmental Design - LEED[34] in the United States, certified by the United States Green Building Council (USGBC). But there are some other like Green Globes Certification[35] in the United States and Canada, CASBEE[36] in Japan. This whole building qualitative assessment schemes might differ considerably from one another, especially on the measurement scales, on the performance-based requirements and on the identified criteria [80][44]. For example, BREEAM includes as criteria for assessments energy, transport, pollution, materials, water, land use and ecology, health and well-being. Whereas LEED uses criteria like sustainable sites, water efficiency, energy, materials and resources, indoor environmental quality, and process and design innovation [44]. At times it can be challenging and time consuming to decide which standards, certifications or rating programs are most credible and applicable for a building construction project.

Studies of LEED certified buildings[37] revealed that energy, carbon, water, and waste

[30]https://www.bca.gov.sg/
[31]https://www.energystar.gov/
[32]http://www.buildup.eu/sites/default/files/content/215_23168_file.pdf
[33]https://www.breeam.com/
[34]https://new.usgbc.org/leed
[35]https://www.thegbi.org/green-globes-certification/
[36]http://www.ibec.or.jp/CASBEE/english/
[37]https://media.alpinme.com/pws/LEED-Costs-Benefits-ROI1.pdf

can be reduced, resulting in savings of 30 to 97% respectively. Operating costs of life cycle buildings can also be reduced by 8–9%. Many sustainable buildings have also seen increases of up to 6.6% on return on investment, 3.5% increases in occupancy, and rent increases of 3%. Other benefits of life cycle buildings include healthier indoor environment and increases in natural daylighting. [80] In conclusion the effort for earning a certification for a construction, even the certification is a voluntary one like BREEAM or LEED, it is an effort that translates also into a valuable marketing tool [44].

Energy Performance Certification Systems

A special kind of certifications are those that focus on the energy performance of buildings. The European Directive on Building Energy[73] states that Member States should apply national energy efficiency schemes for the providers of energy services, energy audits and for other energy saving measures [72]. There is some effort towards energy standards, where enterprises can certificate themselves in one of the available certifications:

- EN ISO 14000 - Energy Management Systems
- EN 16247-1 - Energy Audits
- EN ISO 14000 - Environmental Management Systems

According to the European Directive, Member States need to require that, when buildings or building units are constructed, sold or rented out, the energy performance certificate is shown to the eventual new tenant or buyer and finally attached to the selling or renting contract[71].

To help the Member States of the European Union to reach the goals for energy efficiency, the International Energy Agency (IEA), where Austria is also a member of[38], developed a set of energy efficiency policy recommendations. For the buildings sector, the IEA set up also some guidelines for certification schemes of buildings. The IEA identified supporting mechanisms for robust, accurate and cost-effective certification schemes [44], with the goal to improve the quality and reliability of building retrofit[39] services ([45] and [21]). This mechanism are:

- validated assessment procedures, proper monitoring systems for compliance, quality assurance procedures (e.g. energy audits) which increase the value of efficient buildings and can stimulate the real-estate market
- technology and administrative systems to coordination and maintenance
- training of the assessors towards a qualified workforce

The IEA recommends the following plan for developing and implementing energy certification schemes [44]:

[38] also non-EU countries, e.g. Korea, Japan, the USA are part of the IEA

[39] retrofitting refers to the addition of new technology or features to older systems

- Plan
  - define the terms of reference of the certification scheme
  - develop an appropriate policy framework, deciding if the certification scheme should be voluntary or mandatory one.
  - develop an action plan
  - enrol different actors including the stakeholders
  - be realistic by setting a proper time frame and by allocating sufficient resources (technological and administrative, institutional, financial and human) in order to avoid delays
- Implement
  - provide trainings to assure well-qualifies building assessors
  - raise awareness of the planed scheme in industry and among the public
  - ensure proper management of building data (collection, review, publishing)
  - evaluate adaptability for possible future changes
- Monitor
  - monitor the performance of the certification scheme
  - monitor the performance of the assessors
  - publish results to the stakeholders
- Evaluate
  - assess if the goals were met. Some international assessment schemes are LEED[40] (USA), BREEAM[41] (UK), SIMAPRO[42] (NL)
  - adjust schemes if needed
  - expand the scheme to support other policy measures

According to IEA, certifications should be applied at the design stage (to influence construction) and at completion (to increase compliance and to record the actual performance). Some countries (such as Sweden) require re-assessments of actual consumption after two years.[44]

The person or company that emits energy performance certificates has to assure that the certificates are accurate, reliable and compliant with the national energy performance calculation methods, otherwise penalties may be applied. Each member state has it's own methodology for the qualification and accreditation of certifiers. An analysis of the requirements for certifiers qualification in different countries is presented in one of the BPIE reports[22].

[40] https://new.usgbc.org/leed
[41] https://www.breeam.com/
[42] https://simapro.com/

As a conclusion we provide a holistic view on the described standards and certifications in Fig. 1.7. The PassivHaus standard and certification system aims at designing and evaluating the best performing buildings, whereas the LEED and BREEAM certifications focus on evaluating buildings not only from the energy performance view, but also from the sustainable point of view, where a building is monitored also on its environmental impact from construction to demolition. The SAP standard and the EU Standard EN 16798 are designed according to the European Directives. The ASHRAE and the ISO standards are internationally accepted. The ASHRAE 55, EN 16798 and the SAP standards offer calculation methods for the energy performance of buildings. Since buildings are of a different kind (old and new, manually or mechanically operated, residential or commercial) these standards may or may not adapt their calculations according to the different building types, which makes the calculations methods complex and inaccurate. The PassivHaus focuses only on newly designed buildings and aims at providing the best design and best construction materials for buildings with the best energy performance (see also Fig. 1.8).

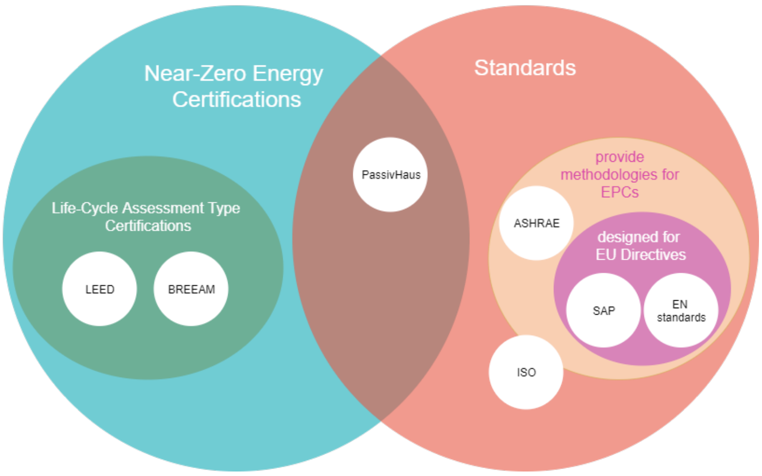

Figure 1.7: Assessment Fragments

Country Particularities on Building Certifications

Certification schemes are implemented differently in each EU country, as directed by the European Union. This is due e.g. to cultural differences or geographic location.

The European Member countries were analysed under the aspect of the certification schemes they use, in particular the compliance with the EU Directives and the performance of implementing these regulations. Among the resulting reports we mention [10], [3] and [20]. The identified differences include:

- The issuing authority differs greatly from country to country.
- The way of implementing the guidelines differ greatly from country to country.

To display the differences we enumerate a few European countries.

The Austrian Institute of Construction Engineering (OIB)[43] designs standards and

[43] https://www.oib.or.at

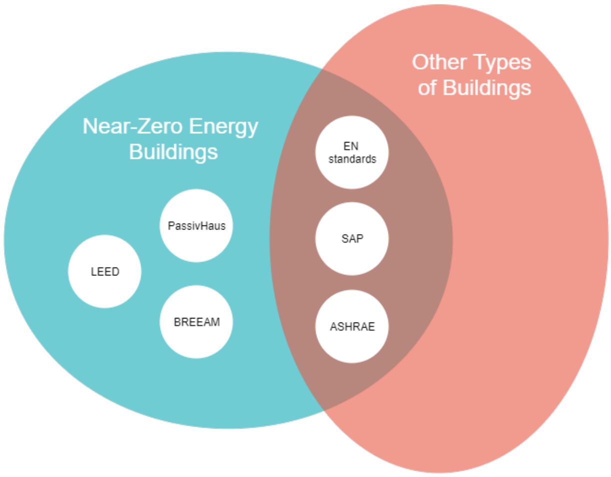

Figure 1.8: Assessment aim according to different types of buildings.

other technical regulations by harmonising the nine "building codes" (of each Austrian Federal State) and other laws. The institute also offers guidelines for implementing these standards. In Austria the energy performance certificates called *Energieausweis* are used since 2008. According to [10] the Austrian certificates are complicated to understand and still not detailed enough to offer transparency. Recommendations to improve energy efficiency are not always given and are not always clear. The certifications may be issued by authorised experts of different fields (e.g. construction, engineering or energy), but it is not required by law that the experts attend special trainings with focus on energy inspections. In Austria, the PassivHaus buildings are graded with the A++ label, where as the low-energy buildings with A+ (see figure 1.9)[50].

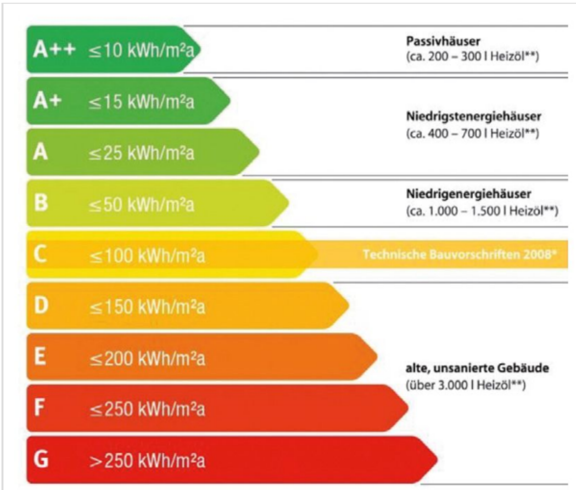

Figure 1.9: Energy Certificate Grading Scale [50]

In order to align to the European Directives, starting with 2020 no A+ or A++ labels are allowed in Austria[1] any more, only A to G will be granted. An example of an Austrian *Energieausweis* is listed in Appendix A.

In Romania, as in other EU countries as well, the availability of a certification is mandatory when a dwelling is sold or rented. Valid labels are from A to G. The requirements for a professional in order to be certified for awarding energy certificates are different to other countries and this requirements are: a relevant university degree, 10+ years of working experience in construction or a related field and a previously successfully graduation of a special training on energy audits.[15] An example of a Romanian *Certificat energetic* is listed in Appendix B.

In the United States the (mainly) voluntary *Home Energy Rating System (HERS) index* is in use. It is a comparative label offering information on the certified building's ranking compared with similar buildings. Buildings are rated based on their actual energy performance and the ranking score is calculated according to the RESNET certification systems.[44] The IECC (the International Energy Conservation Code) regulates the design and construction of energy efficient buildings.[48] This Code is the basis of the HERS scale. Buildings conforming to the current[44] *IECC* regulations are rated 100 on the scale, while 0 represents the energy performance of a zero-energy building. Most building in the US are rated with a score of 100 and above.[44] The US building stock needs improvements, similar to the EU building stock.

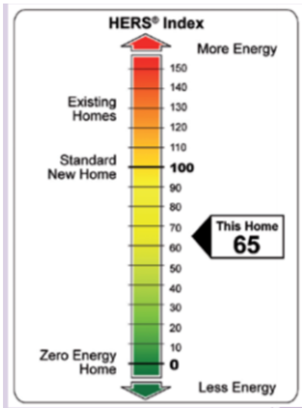

Figure 1.10: HERS index in the US. *Source: iea.org*

In Denmark, energy-labelling of buildings is mandatory. Denmark's Energy Performance Certificate is overseen by the Danish Energy Agency and the Danish Enterprise and Construction Authority. [?] The certificate must be provided during both purchase/sell and rent transactions. Buildings are rated from A to G, where A is divided into A2020, A2015 and A2010. A2020 covers low energy buildings, while G-labelled buildings consume the most energy.[2] An energy consultant inspects the building and according to the undertaken calculations, the building is rated. This labelling scheme is a theoretical one, the rated energy consumption with calculated one and is not a measured net energy rating. A particularity of the Danish system is, that the certification includes recommendations for energy improvements for the rated building. These recommendations do not replace an in-depth energy consultation, but it offers first indications for next energy efficiency actions. The Annex 3 shows an example of a Danish

[44] https://www.hersindex.com/

EPC. The Danish EPC Database is publicly available [45] and serves as an example for other countries. [52] The Danish Energy Certification Scheme was a model for other countries.[44]

In Germany, as in other EU countries, an energy certificate is mandatory when renting or selling a dwelling. Similar to Denmark's approach, a German *Energieausweis* offers recommendations on how to improve the energy efficiency of a building. The German design for an energy certificate is a result of a large field testing of user comprehension regarding the issued certificates. An *Energieausweis* may take 2 forms, similar to the UK certificates, depending on the scope of use: *Bedarfsausweis* (Building Energy Rating certificate) or *Verbrauchsausweis* (Display Energy Certificate). The energy classes, for both forms, are from A+ to H. In a *Bedarfsausweis* the calculated (the theoretical) energy consumption is displayed, whereas in the *Verbrauchsausweis* the real energy consumption used for heating is measured over 36 months and summarized per year. This results in a specific energy class which is the displayed on the certificate. Both certificate types include on their last page, recommendations for energy efficiency measure. This recommendations are presented in a user friendly way, e.g. "The replacement of the windows with new one of U-Value 1,2 and g-value 0,6; amortized in 9 years of usage." An example of the German energy certificate is presented in Annex 5.[19]

1.2.4 The Energy Performance Gap

The role of an Energy Performance Certificate (EPC) is to inform about the energy performance and the energy costs of buildings [75]. The current situation regarding Energy Performance Certificates is not yet ideal, because in most of the cases these certificates do not reflect reality. There is a gap between the predicted energy consumption, which is graded with an EPC rating, and the real, measured, energy consumption of the building or dwelling.

The term "performance gap" refers to the difference between the predicted and the measured energy performance.[17] A "positive gap" is when a building receives a lower EPC rating, but actually performs better. A "negative gap" is when a building receives a higher EPC rating, but actually performs worse. Good energy performance means to achieve low electricity and fuel use, while keeping occupants comfortable.

The existence of a performance gap is a problem, because the rating influences the selling/renting potential of a building or dwelling and misleads in terms of operational costs of a building/dwelling. In [46] it is demonstrated that the same building is rated differently by individual experts. Experts have different views on which measurements of a building are relevant and are ought to be included into the energy modelling and which are not relevant [75],[46]. In a simulation tool, a modeller has to decide which building parameters are to be included and which not for the calculation of the energy prediction. Since the views on the importance of some parameters differ, or in some cases there is not enough data for some parameters in order to be used, it might result in a wrong energy consumption prediction. Such predictions are mandatory to be able to comply with the national building codes, but the predictions are not accurate, because

[45] https://sparenergi.dk/

there is a clear gap between the simulated energy consumption and the real energy consumption.

Other reasons for the gap, which we also saw in previous chapters, are the uncertainties like the behaviour of the occupants or the weather data. Even if the experts would agree on the inclusion of the same parameters in their predictions, the uncertainties may lead to inaccurate predictions.

A further reason for the gap is not respecting the design features in the construction and in the operation phase of a building. During construction the materials that were considered in the design phase might be substituted by other materials, due to various reasons. And during the operation phase, the users of a building or dwelling might behave totally differently than the designers predicted, in case they predicted user behaviour at all. The research conducted in [38] found that an average deviation of 30% occurs between the estimated and real consumption. A similar study [78], where different kind of buildings (schools, libraries, hotels, offices) were analysed, showed that the buildings performed in average 3.8 times higher than the design estimate. The latter study took a look also at the Building Emissions Rate (BER). BER gives the estimated rate of CO_2 emissions per m^2 floor are for emissions from regulated energy use (heating/cooling, ventilation and lighting). [78] [76]

A further problem is that the Building Emission Rate and the Energy Performance Certificate do not capture all energy used in a building. A Display Energy Certificate (DEC) has an A to G rating, which is calculated based on the first 12 months of metered energy use. The DEC takes into account all energy use [76]. The usage of more than one low-energy system, which is encouraged by e.g. BREEAM, causes quite some problems, because the systems tend to get in each other way and the overall performance of the building is worsened [76] [76]. According to[78] the predictions are overoptimistic, since it is expected that the installed systems work perfectly, but in reality some systems (especially the renewable energy systems) need a better handover to the users and are also more difficult to maintain than traditional systems. Typically, energy modelling happens in the design phase only to achieve compliance with building regulations. [76] and [42] suggest that a building design should have in focus the "performance in use", so a DEC instead of a EPC. A further suggestion is to use benchmarks for the type of building, since benchmark-based predictions are within 15% accurate[46] [76]. The automated reading of meters and the building monitoring offer data on the actual performance of buildings, but there still lacks data on the root causes of the energy performance gap.[17] The Measurements can lack on accuracy, or completeness of information. [18]

As presented in the previous paragraphs, the causes for an energy performance gap are diverse. Summing up, the causes for the energy performance gap are [46], [78], [38], [42], [18]:

- the difficulties during concept and planning (lack of consistency in defining targets and how this targets can be met and assessed)
- the building energy modelling difficulties during design (the difference in the literacy of energy professionals, the usage of different calculation methods and

[46] A comparison tool is offered by Carbon Trust, available at http://www.carbonbuzz.org/

simulation tools, the shortcomings of the simulation tools), also the inaccurate predictions of energy use at the design stage provided by simulation tools

- the specification changes before and during construction with no re-evaluation of the energy performance, overestimated quality of materials which are tested and labelled only under test conditions, variation in material properties and dimensions
- the errors during construction/workmanship/installation
- the overly complex control systems and the usage of different low-energy systems aiming at the same type of energy saving, also the degradation of the performance of these systems in time
- the rushed or incomplete commissioning
- the unanticipated occupant behaviour, the facility management
- the weather conditions

Pieter de Wilde[47] identified in his research different types of performance gaps. These vary over time and context. The 4 identified types of performance gaps are [18], [16]:

- Type 1 gap: describes the gap between the energy models at design stage and the measurements on the final building.
- Type 2 gap: is the gap between machine learning methods and measurements from real buildings
- Type 3 gap: the gap between the energy ratings provided by compliance test methods and display certificates from the legislation
- Type 4 gap: is the gap between normative methods used for compliance (e.g. SAP calculations) and the measurements on the actual building. For example the SAP methods do not calculate the energy related to "unregulated loads" (meaning not regulated by Building Regulations) such as electric and gas appliances. The simulation tools tend to underestimate the electrical loads for appliances, because their usage is not know at the design stage.

Some suggestions on eliminating the performance gap, are mentioned by Pieter de Wilde in his papers [16], where "the performance gap can only be bridged by a broad, coordinated approach that combines model validation and verification, improved data collection for predictions, better forecasting and change of industry practice". According to [46], in order to close the gap, it is important on one hand to teach building physics to the energy modellers and on the other hand to receive feedback after a building is commissioned so that lessons can be learned and the prediction mechanism can be

[47] https://www.researchgate.net/profile/Pieter_Wilde

improved. The introduction of more strict regulations might contribute to the reduction of the performance gap.

For the government the performance gap means, that the near-zero energy homes do not contribute as expected to the national energy reduction plan. For the occupants it means that energy bills might be higher than expected and as result the confidence in near-zero homes (including certificates) have to suffer. [42] An effort by the EU to lower the energy performance gap and to monitor and assess actual building performance is the Horizon 2020[48] project, which supports the development of future methodologies and improved tools.

Some suggestions of innovative tool categories are listed in [12] and include improvements in 3D Imagery Tools, Building Information Modelling (BIM), Smart Building Components, Energy Efficiency Quality Checks, Indoor Air Quality and Airtightness Test Tools, Thermal Imaging Tools and Acoustic Tools.

1.3 Low-Energy Buildings

The term *low-energy building* is a more general approach, where as *near zero energy buildings*, the *passive house standard* and *the life cycle assessments* are more restrictive.

A nearly zero-energy building is defined in the European Directive [71] as "a building that has a very high energy performance [...], the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". The passive house standard focuses on the reduction of energy to bear minimum. It's benchmark on energy savings are of a better performance than a typical low-energy building. The life cycle assessments on buildings focus not only on the energy performance but also on the environmental issues from construction until the demolition.

Smart buildings are not necessarily energy efficient, but are more technically equipped e.g. with smart meters. The used technologies inside a smart home are used to monitor and improve the building's energy performance.

Alfonso: The question really is: Does automation improves energy efficiency? I think that the real answer is that ICT allows user to communicate on an understandable way with the building, and with this cut on energy waste.

This information is then used to automate various processes, from heating and ventilation to air conditioning and security.[8]

The investigated features of a low-energy building are:

- Heating and DWH.
- The electric energy consumption.
- Renewable energy gained from solar panels, photovoltaic solar panels or other sources.

[48] https://ec.europa.eu/programmes/horizon2020/en

Low-energy buildings do not imply that there is no need for energy in the process of heat and energy generation. For low carbon buildings this is of importance, because this kind of buildings incorporate renewable energy systems that save the same amount of carbon that is discharged due to the energy used. [63]

A building receives energy from the public energy grids, which is measured. A building might also generate for it's own use renewable energy, which is not measured. And finally, a building might export the excess energy back to the energy grid, which again measured. By subtracting the exported (excess) energy from the received energy we get the net energy use of the building. This concept of *net energy* is introduced in ASHRAE-100 and contributes to the ratings of low-energy buildings.

Low carbon building is one that uses significantly less energy and emits less carbon than current industry benchmarks while providing a comfortable and productive space. ow carbon buildings are not necessary more costly to build, but should definitely be more cheaper to operate. [76]

1.3.1 Requirements

In order to follow the European Directives on energy efficiency, each Member State is developing energy performance assessment and building certification schemes. Some of the features of this methods required by the EU are [23]:

- the developed tools should be more reliable, user-friendly (in terms of clarity and accuracy), cost-effective and should reflect the smart-readiness of buildings
- the quality and reliability of Energy Performance Certificates across the EU should be comparable. The EU encourages the development for new certification schemes, that improve the effectiveness of certificates and which can be deployed throughout the Union.
- the energy performance methodology should be technology neutral
- international and European standards should be used
- the schemes should assess the buildings in a holistic way over the envelope performance, system performance and the smart readiness of buildings

With the Horizon 2020 EE5, Next-generation of Energy Performance Assessment and Certification, the European Union drives the research towards more efficient methods for developing energy performance certificates. The next-generation energy performance assessment schemes "will value buildings in a holistic and cost-effective manner across several complimentary dimensions: envelope performances, system performances and smart readiness".[24]

The next-generation energy performance assessment schemes should:

- be based on an agreed list of parameters/indicators
- take into account building energy related data from sensors, smart meters, connected device

- contribute to the improving the effectiveness of certificates

TODO: Place the below bullet points at the right place

* Goal: Assuring that labels and certificates can be derived from data and present the building state and change possibilities well to the user. The labels can be designed with ontologies in the background to bridge data and the users.

* Requirements: If the labelling method is too complex then it will not be used and a random label will be placed. If the method is too simple, then it might not be accurate enough.

* There is no correlation btw. label and energy efficiency, the methods are not good enough and is subject to interpretations by users.

* Certification costs can go up to 10.000 US Dollars (see EDGE-App)

1.3.2 Challenges

Reducing energy consumption is a noble goal, but there are a number of issues that the low-energy buildings have to find a proper solution for.

The air quality inside buildings is an important aspect that need not to be overlooked. Poor indoor quality is responsible for many diseases among them asthma. Air quality could be fixed by smarter design and energy efficiency measures which in turn yields energy savings and reduces climate the impact. [60] Artificial air flow is introduced in many buildings, also the PassivHaus standard includes such solutions.

The term energy efficiency sounds appealing, but it is not evident what the exact measures are to achieve lower energy consumption. This gap is partly filled by e.g. the recommendation messages on energy consumption bills. But more concrete measures are needed in order to achieve the goals of the European Union.

1.4 Hypothesis

- Data-feedback classification of buildings is better than manual certification.
- Uplifting a building results to a higher classification level
- This proposed methods are more accurate than the existing certifications methods.

Chapter 2

Related Work

Anna: it would be useful at the start of the state of the art sections to mention/explain their subsections: what they are about and why they are relevant (for your thesis question).

2.1 Frameworks

2.1.1 Smart Buildings

Smart Homes are technically equipped dwellings that are able to monitor and improve their energy consumption. Extending this idea to buildings, we have the term Smart Buildings. Smart Buildings are energy-efficient, technically integrated, safe and sustainable buildings that are part of larger energy grids.

IoT

The Internet of Things (IoT) jumps on board on the challenge to lower the impact of humanity on the environment. One of the techniques that is already in use is home automation. The smart meters which are installed in buildings, together with sensors and actuators, keep track and even optimise the energy consumption of a dwelling. Smart Meters are technical devices that measure automatically the energy consumption of a building unit. In the European Directive for Energy Buildings [72] at least 80% of energy consumers should be equipped with Smart Meters systems by 2020.

The goal of the usage of smart meters is the ability to offer accurate and frequent billing details. Artificial Intelligence and Machine Learning technologies might enhance Smart Meters in the future so that the Smart Meters can manage and improve the energy consumption levels of a dwelling autonomously. [53]

By interconnecting homes, offices, data centers, warehouses and the public infrastructure, Smart Cities are born. European cities are actively working on ideas and prototypes in order to accomplish the vision of Smart Cities. An example is the city of Innsbruck, where "the vision of a holistic energy identity in 2050 is only possible by an overall consideration of the city as a system in which energy, buildings, supply networks, mobility, information and people are viewed in an integrated manner." [13]

Smart Readiness Indicator

As we have seen in the introductory part of this theses, the Smart Readiness Indicator (SRI) is a rating that reflects the capacity of a building to operate energy efficient, to be a valuable component of smart energy grids and to adapt to the occupant's needs. The concept of SRI was introduced in the EU Directive 2018.

TODO: Follow up. The additions to the EU Directive 2018 regarding the Smart Readiness Index will be published mid 2020.

The SRI assessment procedure takes into account all the smart ready services available in a building. Each of this services is analysed and graded according to its smartness (integration, flexibility, performance). Some services might function better in regard to the occupant's needs or to the situation of the grid, and some services might perform weaker. This functionality levels describe how smart a service is. The Smart Readiness Indicator is an addition to the already available energy performance rating levels.[79]

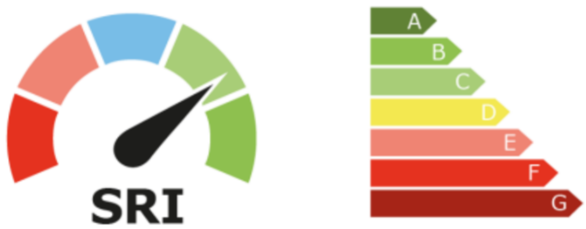

Figure 2.1: Smart Readiness Indicator as an addition to the energy performance ratings of buildings. *Source: buildup.eu*

A proposal for a methodology was presented in a technical study commissioned by the EU ([79]). Eight viable criteria for determining the SRI were found to be of most significance, these are:

- saving capabilities (e.g. better control of room temperature settings)
- flexibility towards the energy grid
- self-generation of energy
- occupant's comfort (thermal, acoustic, visual)
- convenience (e.g. less manual settings needed to be done by users)
- healthy indoor climate
- maintenance and fault detection
- and user-friendly feedback to occupants

These criteria are weighted differently, according to the importance of their impact. Whereas each criteria is the weighted average of 10 domains scores. These domains are: heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, on-site renewable energy generation, demand-side energy management, electric vehicle charging, monitoring and control. Furthermore, the services available in a building are grouped by the aforementioned domains. Each service receives a grading called "functionality levels". Only services are graded that are present and relevant. Missing services don't impact the score, if the missing service is not relevant. Finally the functionality levels of services are combined to a final result which is the smart readiness index.[79]

this makes the rating nice and flexible, but how is the score of one house comparable to the score of another house? Only similar houses can be compared? Which means the rating is relative?

A further methodology is presented in [56], where the focus is on rating the capability of buildings to interact efficiently and bidirectional with the grid. In this context the buildings are viewed more as *prosumers* (consumers and at the same time producers of energy). Prosumers would receive the highest SRI rating.[56]. If a building has no storage or load shifting potential, but it is connected to the grid, then this building is a consumer and receives the lowest SRI rating. On the other hand, buildings that are not connected at all to the grid, are not rated. This methodology provides mathematical formulas for calculating the SRI. The values needed are:

- the energy demand of the building per energy source for the selected time period
- the storage capacity of the respective storage in the building
- the efficiency factor of the storage capacity (loading and unloading)
- storage loss during the selected period in full storage (e.g., self-discharge, heat losses)
- and the activity coefficient of the building

The proposed SRI rating in [56] always needs to be calculated per energy grid (electrical, thermal, gas). The benefit of the separation of ratings per grid type is, that buildings with no connection to the grid (for example buildings with no connection to a thermal network) are not disadvantaged, only the SRI for the particular grid type will not be available. The proposed SRI does not reflect the energy efficiency of the building, as this is already part of current energy performance certificates. In conclusion the energy performance certificates would need additional input data related to the building's storage system (if such a system is available) and some data regarding the ability to interact with the grids, in order to calculate the SRI rating.[56]

One of the Horizon 2020 funded projects which, aimed at delivering a way to evaluate the smart readiness of buildings, was ExcEED[1], standing for "European Energy Efficient building district Database". Since the end of 2019 the project was renamed to "enbuibench", standing for "energy and comfort building performance characterization and benchmarking platform". During the EU funded project a database was created and a UI platform was developed. In this database energy performance data (primary energy consumption, total heated floor area, occupant comfort etc.) was collected, based

[1] http://www.exceedproject.eu/

on the input of building owners and building users. The developed ExcEED platform contains a set of Key Performance Indicators (KPIs), that help the users evaluate the smart readiness and also the energy performance of their building.

Integration Framework for Smart Homes

The SESAME[2] Project offers a plug-and-play solution for integrating building automation systems with the advanced metering systems of a building in order to facilitate an energy-aware home automation system[29]. The project uses Semantic Rules to describe how appliances within the environment will be operated. This rules enable reasoning on the measured data.

For the SESAME Project three ontologies[3] were developed[74]:

- The Automation Ontology includes general concepts such as Resident and Location, but also concepts in the automation and in the energy domain, such as Device (with consumption per hour, peek power, on/off status), and Configuration (configuration data of an appliance).
- The Meter Data Ontology enables communication protocols for data exchange with the metering equipment.
- The Pricing Ontology is used for selecting the optimal tariff model for a specified time and energy load. It defines weighted criteria which are then used by the reasoning engine for choosing the best tariff model.

2.1.2 Energy Consumption Awareness Framework

The Entropy[4] Project aims to sensitize tenants for the consumed energy of their dwellings. This dwellings are equipped with special sensors that collect energy consumption data. The tenants are kept informed by a specially developed application about their energy consumption. The Entropy Project focused mainly on the behaviour of the tenants and suggests via their services lifestyle changes in order to reduce the energy consumption, but in a user-friendly manner.

As described in the article [32] the Entropy services are collecting and processing data from sensor nodes in real-time and managing historical sensor data. The Entropy Project uses Semantic Web technologies like semantic models and ontologies for a unified data representation of the previously collected sensor data. The two developed semantic models were on one hand, the Energy Efficiency Semantic Model, represents the energy consumption data collected from the sensors and on the other hand, the Behavioural Semantic Model has it's focus on the energy consumption profile of end-users. This models facilitate the further management and exploitation of the collected sensor data. With the help of LinDa[5] workbenches the semantically annotated data from the

[2]SESAME stands for SEmantic SmArt Metering

[3]Ontologies are a set of concepts and categories in a subject area or domain that shows their properties and the relations between them (Wikipedia)

[4]http://entropy-project.eu

[5]http://linda-project.eu/tools/

semantic models are transformed into linked data[6]. This approach is of use to the building sector because comparisons between the collected data and also the exchange with other open linked data like meteorological data is needed. The data is stored in JSON-LD[7] data format, which is a lightweight linked data format. The recommender system[8] behind Entropy is based on the Drools[9] framework, which is a rule-based management system. In the Entropy Project a rule is expressed by a condition element and a recommendation template. For example if a context changes the recommender system creates a personalised recommendations for each user in the targeted user group by using the recommendation template. The targeted user group, are users that satisfy a specific user attributes defined in the template. Through the Entropy project an application was developed, which joins energy and behavioural data and in consequence leads to the improvement of energy efficiency in smart buildings.[32] The Entropy's recommender system, uses machine learning techniques, provides the user with personalised suggestions taking into account the user attributes and behavioural traits.[31]

2.1.3 Energy Consumption Prediction Framework

"Building thermodynamics is a complex non-linear phenomenon, which is strongly influenced by weather conditions, building operating modes and occupant schedules."[34]

Predictive data-driven models were presented in [34]. These models were developed with the help of machine learning techniques. The machine learning algorithms are trained with a set of data and run on a different set, so it applies what it learned during the training period. The developed predictive models were of two categories, on one side the black-box[10], in contrast to white-box model [11] models (e.g. SVR[12], Regression Forest[13]) and on the other side, the grey-box[14] models (e.g. Gaussian[15]). The mentioned research proved that the predictions generates by the black-box models which were applied on temperature values were outperforming the grey-box models which were

[6]Linked Data are interconnected data which are useful for semantic queries, http://linkeddata.org/

[7]https://json-ld.org/

[8]A recommender system predicts the preferences of users and is mainly used for generating recommendations for products and media content.

[9]https://www.drools.org/

[10]The black-box models are purely data-driven models where the input data is not known in forehand, but a training set of the on site measurements of a building is needed. It uses statistical or machine learning modelling approaches

[11]The white box models are models that need detailed information of the physical characteristics of a building which has to be already available in forehand (e.g. the results of visual inspection, of information taken from design plans), before the model is applied. White-box models are not suited for online solutions.

[12]Support Vector Regression (SVR) is a variant of Support Vector Machines (SVM) that fits the optimal curve out of which the training data does not deviate more than a small number ϵ).

[13]The Regression Forest Model takes the average of the prediction of each regression tree, where a regression tree is a variant of decision trees, designed to approximate real-valued functions, instead of being used for classification methods.

[14]Grey-box models are a hybrid-model, where physical-data model and data-driven models are combined

[15]The Gaussian distribution is used to represent real-valued random variables whose distributions are not known

applied on energy consumption values, because the first ones were capturing human behaviour. The human behaviour has a greater impact on the energy consumption that the envelope of the building. According to the researchers, among the black-box methods, the Random Forest had the best prediction results.[34]

2.2 Tools

2.2.1 Building Energy Simulation Software

"The approach of building simulation is to create a virtual building where the user can specify in detail parameters that influence the building performance, with resulting performance predictions that are as close to reality as possible."[28]

Most of the energy simulation software, among which the best known are EnergyPlus[16] and TRNSYS[17], are white-box simulation programs. They simulate a building based on the explicitly introduced building details and calculates with the use of complex mathematical formulas the energy consumption of the building. [34]

EnergyPlus is a mature and elaborate simulation software for buildings. It is targeted at expert users, engineers, architects and researchers. EnergyPlus was used for evaluation of results e.g. in the paper [64] and many more. With the help of EnergyPlus, which is a free, open-source, cross-platform software expert users can model the energy and water consumption, the lights, the air quality, the DWH and much more. The most important feature of EnergyPlus is that it is very easy to use in a machine to machine communication. The building data is fed to the program with the help of input files, and the result of the calculations of the program is produced in output files.

The Transient System Simulation Tool (TRNSYS) is a wildly used simulation environment, developed mainly for thermal and electrical control systems, but it can also be used for other transient systems. In contract to EnergyPlus, TRNSYS is a commercial tool. TRNSYS is a versatile component based software system, where component models may be selected from the build-in libraries, or written by the user and linked to the main TRNSYS simulation model. TRNSYS also supports machine to machine communication, since it also has the ability to connect to the interface of other systems or simulation tools. [69]

The most important capabilities of a simulation tool are [46]

- usability
- computing ability
- data-exchange
- database support

This kind of systems require detailed information of the simulated building, information that is not always available.[34] This lack of complete information is one of the causes of performance gaps.

[16]https://energyplus.net/
[17]http://trnsys.com/

Building Assessment Simulation Software

Building simulation tools model the important aspects of physical behaviour of buildings. A classification of building simulators can be found in [63]. The classification criteria are

- by how a model is created
- by the levels of dynamisms of the model
- by complexity e.g. calculation based methodologies like SAP, the PassivHause project or benchmark simulators like EnergyPlus

The weather but also the behaviour of occupants are of a great impact on the comfort level of a building and at the same time they are hard to predict. The designs that takes into account this uncertainties will be more reliable[63]. Uncertainties are categorised as [63]:

- Environmental: climate change
- Quality of building materials and the quality of finishes
- Occupancy Dynamics: cooking habits, door and windows openings by occupants, the use of appliances

The specificity of the information provided is important in determining whether the building owners implement the advice. The more specific the recommendation, the larger the impact – but the costs of the advice may be higher. If, for example, the recommendations are automatically generated by the assessment software, costs are reduced, but such recommendations would be less specific and accurate for the building, which weakens the impact of the advice. More specific advice provided by a building professional is more expensive but is more likely to provide appropriate cost-optimal solutions and relevant details to motivate the building owner to undertake the upgrading measures. [44]

2.2.2 Building Certification Software

A building certification software calculates energy performance and ratings based on annual energy use, e.g. annual kilowatt hours used per square meter (kWh/m^2/year) or related CO_2 emissions, measured in kilograms of CO_2 per square meter (kgCO_2/m^2/year).

Certification software ensures the quality of the certification as it facilitates standardised calculations. A comprehensive software system may also provide recommendations for upgrading the building to improve efficiency.[44]

As an example, the EDGE-App[18] is a comparative software and a certification utility. This application is location and climate aware and it suggests possible certification companies, including their contact data, after the user entered the available building measurement values.

[18] https://app.edgebuildings.com/

2.2.3 Building Management Systems

The information gathered from smart meters and also the information displayed on the energy bills might be to technical for normal users, this is why researchers are trying to find solutions for improved visualisation methods which are more appealing to the end user, with the end goal to motivate the user to save energy. The technical equipment is not aware of the interests or of the technical expertise of the user.

Researchers were investigating which kind of visualisation type, tenants are reacting at the most. As reported in [68], the behaviour of tenants was observed in form of a virtual game, where users could see the energy consumption of their virtual flats and define some rules (e.g. shut down the light after 22 o'clock). This rules were automatically applied to the virtual flat and their effectiveness on the energy consumption was inspected.

Among the researched visualisations for the consumed energy, some were:

- the amount of generated CO_2
- the amount of trees needed to absorb the generated CO_2 quantity
- the amount of money spent
- comparison to other users of the game

As a result, the most effective way to visualise consumption was by displaying the costs in Euro. A lower impact had the visual comparison to other users and also the visualisation of the number of trees that was needed to absorb the generated CO_2 [68].

Another study conducted by the founders of an US company called OPower[19] revealed that consumers in the US care a big deal about their consumption when compared to the energy consumed by their neighbours. Social pressure can be influential in the behaviour of tenants [54]. The company OPower, at the time of writing, was successful in aiding energy companies in providing their users with detailed bills and also with recommendations and motivational messages to stimulate their users in saving energy.

Personalised messages have a significant effect on energy related behaviour. This is the result of the research[55] conducted in the UK in social housings. According to the study consumers acted positively when provided with personal messages which contained their personal energy consumption details and also a concrete action plan for energy savings. An example of a personalized message used in the research was: "If you reduced the thermostat temperature in your house one degree you would save 11 kWh; this is equivalent to £1.43." This personalized action prompts were sent out only to the users that were consuming more than the average or more than a set threshold. This is because the opposite effect of encouraging users to consume more energy, in case they are below the average, was not desired.

2.2.4 Energy Efficiency Testing Framework

With the aim of increasing the quality and the accuracy of energy analysis tools, the National Renewable Energy Laboratory (NREL) in the US developed the Building

[19] http://opower.com

Energy Simulation Test for Existing Homes (BESTEST-EX)[20]. It is a test method where energy performance software program is tested against itself for the performance in modelling and prediction of energy consumption.

BESTEST-EX offers two types of test cases: building physics and utility bill calibration test cases. In the building physics test cases[21] the model inputs, which is the building data, is fixed by the test case. The resulting predictions for energy consumption is then compared to the NREL predictions.

The utility bill calibration test case[22] uses empirical data from energy bills of buildings in the US. The software under test receives as input such data and then predicts energy savings. Again, the result is then compared to the NREL reference predictions. This reference predictions are calculated with state-of-the-art simulation tools like EnergyPlus.

The tests comprised in BESTEST-EX are included in the ANSI/ASHRAE Standard 140, Method of Test for the Evaluation of Building Energy Analysis Computer Programs [ASHRAE 2011]. BESTEST-EX can help in diagnosing why a energy performance software has errors, but it cannot evaluate true accuracy relative to how a real building performs as built and as occupied.

The data format which was especially developed for this kind of energy data is called Home Performance Extensible Markup Language (HPXML).[49] HPXML is an open data standard published by the Building Performance Institute (BPI) that makes it easier to collect and transfer home energy data among software tools.

HPXML is comprised of a standardized data dictionary and a standardized data transfer protocol [41]:

- The data dictionary defines the names, definitions, and data formats of terms used in the HPXML standard. It is used to describe a building and includes therms related to contractors, customers, program information, buildings and it's components, building systems, energy efficiency features and systems, renewable energy features and systems, energy consumption and energy savings (estimated and actual).
- The data transfer protocol defines the rules for transferring data defined in the data dictionary between different software systems.

HPXML facilitates the communication and the exchange of information and data on residential buildings and energy performance. A HPXML validator can be found on the HPXML homepage.

In conclusion, BESTEST-EX is a repeatable procedure that tests how well the predictions of energy software tools perform in comparison to the current state of the art in building energy simulation. There is no truth standard, but the reference predictions have undergone validation testing.[65]

[20] https://www.nrel.gov/buildings/bestest-ex.html
[21] https://www.nrel.gov/buildings/bestest-ex-cases-physics.html
[22] https://www.nrel.gov/buildings/bestest-ex-cases-utility.html

Collaboration on Energy Performance

The European Commission funded the *BUILD UP*[23] platform in order to promote and facilitate energy consumption saving measures in buildings. This platform offers information on best practices, available technologies and the current legislation for energy reduction. The BUILD UP platform is open for building professionals, local authorities and citizens, where they are encouraged to share their knowledge.

A complex collaboration research project funded by the International Energy Agency, the European Union and the European Interreg Alpine Space Project ATLAS[24] namely, IEA-SHC Task 59[25], is focusing on exchanging knowledge about energy and CO2 saving methods specifically in historical buildings. The outcome of this project will be the Historic Building Atlas, a database for best practice examples for energy performance measures in historical buildings.

2.3 Building Information Modelling - BIM

Building Information Modelling (BIM) is a current trend in building modelling which consists of computational models in which large amounts of design data (including the thermal characteristics, the costs, the supplier and the weight of building materials) is stored. [63] BIM models allows architects, engineers, constructors and other partners involved in a building project to visualise the building to be built in a simulated environment in all details. As a consequence, potential design, construction and operational mismatches can be detected.[6]

Because of the big amount of data that is used in BIM approaches, some optimisations methods were needed. Some successful algorithms are researched in [63] and among them evolutionary algorithms (EA) which mimic the basic operators of natural evolution (recombination, mutation, evaluation, selection) and Robust optimisation methods which do not loose, or loose very little, of its optimality if the decision variables or conditions change.

Building information models (BIMs) are files (often in proprietary formats and containing proprietary data) which can be extracted, exchanged or networked to support decision-making for buildings[82]. But BIM are not just files, BIM is a way of optimising planning, design, construction and the operation of buildings[51]. BIM is an intelligent 3D-model based process[5].

A building information model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule. The building information model can be used to visualise the entire building life cycle[6]. Furthermore, BIM is an opportunity for integrating data streams and building services with other relevant data.

A suite of commercial tools are supporting BIM, like the Autodesk's software tools:

[23] www.buildup.eu
[24] https://www.alpine-space.eu/projects/atlas/en/home
[25] http://task59.iea-shc.org/

Revit[26] for complete model-based building designs and documentation, Civil3D[27] for improving building design and construction documentation, Navisworks[28] for improving BIM coordination , Infraworks[29] focusing on infrastructure design.

BIM is mainly used for new buildings. For already existing buildings, the conversion of available documentation (digitalised or not) into BIM models can be challenging.[81]

In conclusion, BIM is not just files or just a software, BIm are not just 3D models, BIM is a digital optimisation process, where the goal is to improve the workflow of a building life-cycle. BIM simulates the construction project in a virtual environment and is an effort towards a so called Digital Twin[30].

2.3.1 Standards and Datamodels

An effort for the standardisation of BIM is conducted by *Austrian Standards*[31], the Austrian competence centre for standards. The current standards for Building Information Modelling are [39]

- ÖNORM A 6240-1 defines commands for storing grouped information. This aspect is used in an innovative way by the standard by defining how to file graphic data in a structured way and how to exchange intelligent building data and information.
- ÖNORM A 6241-1 applies to the technical implementation of data exchange and the storage of building information, including alphanumeric data contained in building models that are required during planning and the life-cycle management of buildings.
- ÖNORM A 6241-2 regards the technical implementation of a multidimensional, structured standard data model for buildings. This standard lays the foundation for the comprehensive, standardized, product-neutral, systematized exchange of graphic data and related object data based on IFC (Industry Foundation Classes) and bSDD (buildingSmartDataDictionary), which are detailed further in this chapter.

Industry Foundation Classes (IFC) is an open international standard for the exchange of building information. IFC was developed by BuildingSmart[32], a non-profit industry-led organization.

The Building Information Modeling (BIM) is based on the IFC standard, which defines an exchange format for building information (e.g. graphical data, GIS data, environmental data) and information related to the surroundings of a building[36].

[26]https://www.autodesk.com/products/revit/overview

[27]https://www.autodesk.com/products/civil-3d/overview

[28]https://www.autodesk.com/products/navisworks/overview

[29]https://www.autodesk.com/products/infraworks/overview

[30]A Digital Twin is "a virtual representation of both the elements and the dynamics of how a device works and operates throughout it's life-cycle. It is more than a blueprint, it is more than a schematic, it is not just a picture [...]" (IBM Watson) [61]

[31]https://www.austrian-standards.at/

[32]https://www.buildingsmart.org/

IFC is vendor neutral, but it is supported by different tools for BIM. The format of IFC is XML.

Data exchange can take place if following is known[36]: 1) the format for information exchange is known 2) a specification of which information to exchange (e.g. as defined in IDM - Information Delivery Manual)and when to exchange it 3) a standardized understanding of what the information represents (International Framework for Dictionaries - IFD)

IFD is an open dictionary of concepts and terms, where each item is given an unique identification number (Globally unique ID - GUID) and each term has associated with it a set of names and definitions in other languages, which allows international communication. [36]. The buildingSMART Data Dictionaries[33], are open, shared, language independent libraries, which standardizes all types entities, properties and classifications.

Furthermore, Open BIM[34] is an effort to improve the interoperability of different tools. Open BIM is an implementation of the reference model on an open standardizes platform. Open BIM represents more a movement than a technology.

Is COBie relevant and should be mentioned? COBie = data format for asset definitions

Semantic models

Industry Foundation Classes (IFC) entities are a product model schema containing a load of information regarding geometry, materials, performance etc. A model view represents a layer on top of the later schema, and it offers the possibility for effective data exchange by providing means for data selection. [9]

There are some gaps in the interoperability of BIM tools. One of them is, that the IFC schema is too generic and some concrete meaning of the exchanged information may be lost. One of the efforts to improve the IFC models with semantic meaning is SeeBIM[35].

SeeBIM (Semantic Enrichment Engine for Building Information Modeling) is a framework for enriching IFC exchange files with semantic concepts, which are inferred by semantic rule-engines from the information contained in the building model (BIM). The latter process is called semantic enrichment. The semantics of a building object are composed of its form, function and behaviour. [9]

The inference rules encapsulate the knowledge of domain experts. The rules are defined as IF-THEN rules using a predefined set of object types and operators, expressed in a format easily comprehensible to domain experts. The operators include functions for reading the existing building model, testing for geometrical and topological relationships, and for creating new objects, properties and relationships.[9]

The rules use two types of IF clauses: clauses that test for features of a single object, and clauses that test for topological relationships between pairs of objects. Rules used to identify object types often depend on the prior identification of other relevant, related

[33] https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/

[34] https://www.graphisoft.com/archicad/open_bim/

[35] http://vclab.technion.ac.il/

objects. If the rule set is inadequate, some objects cannot be identified and enrichment will be partial, and in some cases interdependency within the rules can result in infinite loops.[67]

The rich data sets can be analysed, explored, and processed by a formal query language e.g Spatial SQL[36] or GeoSPARQL[37] handles spatial data. But these languages were not suited for the 3D representations used in civil engineering, specifically for the qualitative spatial predicates. Therefore, QL4BIM (Query Language for 4D Building Information Models) was developed as a BIM query language.[67] QL4BIM[38] includes new domain-specific operators for the examination of topological, directional and temporal aspects.

The semantic enrichment engine (SEE) utilizes forward chaining to infer new facts about a model. It consists of the following components[9]:

- A parser, which reads IFC model instance files exported from BIM tools.
- An internal run-time database, that stores parsed objects, relationships and their attribute values.
- The inference rules are compiled by domain expert users and stored in persistent file storage. The rule-sets are described using a three-tiered structure:

  Tier 1, consists of the rule statements. Their lexical components are logical and relational operators, Boolean constants, universal operators (defined in Tier 2), domain specific concepts and relationships and product model schema entities.

  Tier 2, is a library of concepts, properties, and relationships, as well as the geometry, data query and spatial topology operators that are used for compiling rules in Tier 1.

  Tier 3, represents the implementation in computer code of the tier 2 operators.
- An IFC writer, generates IFC files from the semantically enriched models in the database.
- A custom-built run-time rule-processing engine, executes the user-defined rules and adds new facts about a model to the internal database of SEE. The rule processor uses forward chaining, so that derivation of any new fact about a model can trigger further new inferences. Processing continues until no further facts can be inferred.

The import tool should be tailored to the specific MVD, since the import tool should be the tool taht adds semantics to the building model data.[67]

[36]https://docs.microsoft.com/en-us/sql/relational-databases/spatial/spatial-data-sql-server?view=sql-server-ver15

[37]https://www.opengeospatial.org/standards/geosparql

[38]https://www.cms.bgu.tum.de/en/research/17-research-projects/121-spatio-temporal-query-language-for-verifying-and-analyzing-4d-building-information-models

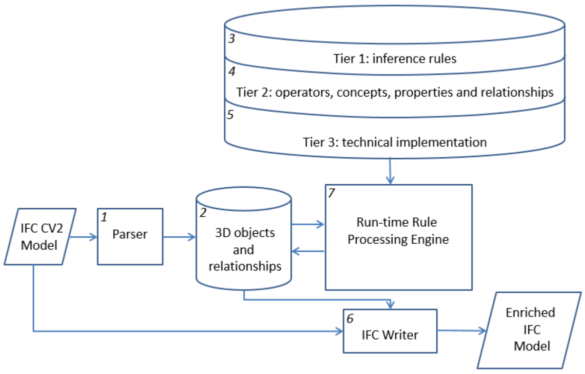

Figure 2.2: Semantic Enrichment Engine (SEE) architecture [9]

BIM Platforms

There are some efforts in improving the collaboration for BIM models.

One of them is the open-source platform *BIMserver.org*[39]. BIMserver.org is on one hand a platform (a base) on top of which developers can build their own online BIM Tools. On the other hand, BIMserver.org and more precisely the apps build on top BIMserver.org, offer a user interface for end users to upload, visualise, query, validate their BIM models.

A further BIM platform is *A360*[40], a commercial tool offered by Autodesk. This platform offers a medium for collaboration between the different Autodesk programs, by offering the possibility to share, view, browse BIM files. Autodesk offers also a cloud based platform for third-parties, called *Forge*[41]. Forge is a platform of web service APIs, it allows the integration of different Autodesk products into third-party web or mobile applications or services. As a drawback for the wide building construction community, is the fact that this tools use proprietary data formats so this approach lacks on accessibility and transparency.[62]

A few other commercial platforms are BIMcloud[42], BIMcollab[43], bim+[44].

In conclusion, Building Information Modelling offers support on achieving proper design continuity, helping to monitor and control design, quality, performance and compliance. BIM provides a collaborative exchange of information from concept through design, construction, handover and operation. [43]

[39]https://github.com/opensourceBIM/BIMserver
[40]https://a360.autodesk.com/
[41]https://forge.autodesk.com/
[42]https://www.graphisoft.com/bimcloud/overview/
[43]https://www.bimcollab.com/
[44]https://www.bimplus.net/

Chapter 3

Requirements and Methods

Anna: For the design of the semantic models and the validation here I would suggest to pick a really specific and small example and focus on it. For example, put up a model and evaluate it if it is clear enough for the user and well as can be instantiated correctly by the data in a very specific scenario. For example, when informing the user and helping him/her to make a decision on whether to install a solar panel or not (Alfonso may have ideas that can be of interest / are likely to work out at the best). Keeping very specific and small would be good, as otherwise you may run into large amounts of work, and then the thesis would be way over the time and effort that should be allocated for it.

3.0.1 Recommender Systems

what it is. Related work: Entropy (recommender system for energy savings)

3.0.2 Use Cases

Statement 1. 'Your house consumes 70Recommendation: 'If you install one meter of solar panel, your house's consumption decreases to 50

TODO: example service for users who consume too much

The return of investment is mostly left to be decided by the user, since they renovate or even sell their house anyway at some point. We can offer 1,2 informative prices in AT.

3.0.3 Methods

Theoretical Background

* black-boy, grey-box

* in the paper "<towards energy efficiency smart building models based on intelligent data analytics" [33]a list of statistical methods used already in solar energy are listed!

* for EAs (evolutionary algorithms see [64])

When designing a mathematical model for buildings, creators how to make a compromise to gather in their model only the most important characteristics in order to be able to model the building as accurate as possible and to be able to run calculations that require a reasonable amount of computational time.[63]

other: `https://e3p.jrc.ec.europa.eu/sites/default/files/11_use_of_data_madsen.pdf`

(`e:\docs\UniInnsbruck\Masterthesis\models\`)

(`https://e3p.jrc.ec.europa.eu/events/methodologies-energy-performance-assessment-b`

3.0.4 Reasoning

How to turn a building in a passive house

Represent building data in a semantic form.

3.0.5 Datasets

- UK Dataset CarbonTrust[1] is a dataset that comprises data measured from condensing boilers between 2004 and 2007 in households in UK. The goal of the creation of this dataset was to assess the carbon performance and to improve future policy decisions. It was an effort to move towards a low-carbon economy, among which to develop and improve low carbon technologies e.g. Micro-CHP technology[2]. The performance data was collected every 5 minutes for one year per heating unit, which resulted in ca. 190 million datasets. The parameters that were measured were:
  - the core electrical and thermal parameters
  - calibration managements
  - temperature measurements
  - operational measurements

  Based on this data the maintainers of the dataset created daily and annual statistics to gather insights on the energy consumption of the monitored households. Data auditing is an important part of such measurements because it ensures the integrity and accuracy of the data.

* Product Characteristics Database, www.ncm-pcdb.org.uk/sap/index.jsp -> BIM; Building Energy Performance Assessment Support website

* UIK civil engineering datasets (AT Data)

* Odyssee-Mure database

* https://passivehouse-database.org/

EPBD data modelling requirements

[1] https://carbontrust.com

[2] Combined heat and power (CHP) systems are small generators that fuelled e.g. with natural gas produce electricity and heat

https://joinup.ec.europa.eu/sites/default/files/document/2015-10/location_data_for_buildings_related_energy_efficiency_policies_-_feasibility_study_v13_-_annexes.pdf pages 27-31

TODO: double check with my own data model

INSPIRE

"INSPIRE is based on the infrastructures for spatial information established and operated by the Member States of the European Union. The Directive addresses 34 spatial data themes needed for environmental applications."

Geo-Spatial Datasets:

* building address datasets (Gebäude Tirol)

* solar radiation (Solareinstrahlung und Solardauer Tirol 2013, Solarpotential)

Sandbox: https://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/use-case-1/webapp/ Web-app with basic building data and energy performance rating (A+ to G)

Maybe useful for manual testing. https://inspire-sandbox.jrc.ec.europa.eu/registry

TODO: try open the datasets with ArcGIS Online or GeoNetwork

Datamodel: http://www.epsilon-italia.it/public/geosmartcity/schemas/gsc-bu2d-energy/2.1/HTM

INSPIRE has data about energyPerformance, the problem is how to get to the data. Identifier: http://inspire.ec.europa.eu/codelist/EnergyPerformanceValue

https://publications.jrc.ec.europa.eu/repository/bitstream/JRC104587/jrc104587_d7.1-usecase1_final_report_v2.0_pubsy\%20pf.pdf (e:\docs\UniInnsbruck\Masterthesis\datasets\INSPIRE\)

https://publications.jrc.ec.europa.eu/repository/bitstream/JRC102276/jrc102276_buildings_related_datasets_in_the_inspire_geoportal_def_pubsy\%20-isbn-issn.pdf

https://publications.jrc.ec.europa.eu/repository/bitstream/JRC102276/jrc102276_buildings_related_datasets_in_the_inspire_geoportal_def_pubsy\%20-isbn-issn.pdf

This layer is released under the terms of the license Creative Commons-Attribution (CCby 3.0). It will be necessary to name the source of origin of the information in the following manner: "geographical information owned by the Government of Navarre." Department of Economics, finance, industry and employment. Free public access: [http://idena.navarra.es] "more information about the terms of use at:

http://www.navarra.es/home_es/OpenData/Datos-abiertos/Terminos-de-uso-deOpen-Data

http://creativecommons.org/licenses/b

TABULA Web Tools http://webtool.building-typology.eu/ http://webtool.building-typology.eu/#bm

Episcope (Austrian Project)

https://episcope.eu/

https://episcope.eu/fileadmin/episcope/public/docs/reports/EPISCOPE_FinalReport.pdf Tabula xlsx Tables for calculating energy demand, but also Building data as floor are, roof size, solar energy variables, U-values

https://episcope.eu/fileadmin/episcope/public/docs/reports/EPISCOPE_FinalReport.pdf

* climate zones in EU-28

* https://episcope.eu/communication/download/usescasesforimprovingenergyconsumptio

* https://episcope.eu/fileadmin/tabula/public/docs/brochure/AT_TABULA_TypologyBrochure_AEA.pdf definition of energy level classes and also a definition for klimaactiv requirements and examples for improvements

https://episcope.eu/building-typology/webtool/

BATH University datasets for papers

* How smart do smart meters need to be (internal temperature, C02, electricity, gas but no floor area): https://researchdata.bath.ac.uk/256/

* Building Performance Gap: Are modellers literate? :only statistics: https://researchdata.bath.ac.uk/221/

* Does insulating buildings increase overheating risk ; includes data for Insulation, thermal mass, window size,Shading,Internal gains,Window opening rubric,Algorithm,Infiltration,Orient https://researchdata.bath.ac.uk/390/

* Probabilistic adaptive thermal comfort for resilient design: climate data are in teh dataset https://researchdata.bath.ac.uk/369/

* Designing sensor sets for capturing energy events in buildings; domestic sensors measuring temperature, humidity, levels of sound, light and carbon dioxide, and power consumption; https://researchdata.bath.ac.uk/241/

* CarbonTrust (from Alfonso) total heat area, building type, orientation of property, low energy light bulbs, efficiency, wall u-value, roof area, total co2 per year,

* EEFIG energy efficiency investment database

http://www.eefig.com/index.php/deep open source database for energy efficiency investment performance monitoring and benchmarking not sure how to access the database data

* UK building stock observatory

EU Building Stock Observatory

(https://ec.europa.eu/energy/topics/energy-efficiency/energy-performance-of-buildi eu-bso_en), a comprehensive database of the building stock characteristics in the European Union. The building data is managed by BPIE since 2010. In 2016 the available data was merged with the data of the European Energy Efficiency building database (ExcEED). The later aims at providing reliable information to designer, energy managers and policy makers. BPIE is involved also in the EUCalc[3] Project which aims for a low-carbon Europe.

The EU Building Stock Observatory tracks many different aspects including (https://ec.europa.eu/energy/topics/energy-efficiency/energy-performance-of-buildings_en):

- energy efficiency levels in buildings in individual EU countries and the EU as a whole
- different certification schemes and how they are implemented
- financing available for renovating buildings
- energy poverty levels across the EU

The Observatory contains a

[3]http://www.european-calculator.eu/

- a database
- a datamapper
- a factsheet

UK:.

https://www.gov.uk/government/statistical-data-sets/live-tables-on-energy-perform only totals per year are displayed or average consumption of a building type per year

*Display Energy Certificate Data https://www.europeandataportal.eu/data/datasets/display-energy-certificate-data1?locale=en EPC rating included!!!! e:\docs\UniInnsbruck\Masterthesis\datasets\Europeanopendata\energycertificatedataforpublicbui csv

* https://www.europeandataportal.eu/data/datasets/energy-performance-of-buildings?locale=en

*https://data.cambridgeshireinsight.org.uk/dataset/domestic-energy-performance-cer

EUROPE:

https://ec.europa.eu/energy/eu-buildings-datamapper_en?redir=1 some statistical data, maybe useful for the ppt presentation, or other general stuff.

France:

* https://www.europeandataportal.eu/data/datasets/diagnostics-de-performance-energ locale=en

* https://data.ademe.fr/datasets/dpe-des-logements

* e:\docs\UniInnsbruck\Masterthesis\datasets\Europeanopendata\France\DPE_logements.csv EPC data!!!!

Poland: * https://dane.gov.pl/dataset/591,centralny-rejestr-charakterystyki-energetycznej-budynkow building consumption data, no EPC rating e:\docs\UniInnsbruck\Masterthesis\datasets\Europeanopendata\Poland\Wykaz-budynkow_1.csv

TODO:

* National Energy Performance Certificate Register

OK, but where is the database?????? looks to be here: https://ec.europa.eu/energy/eu-buildings-database_en?redir=1

https://ec.europa.eu/energy/en/eu-buildings-database

https://op.europa.eu/en/publication-detail/-/publication/420055b1-f1cc-11e7-9749-01aa75ed71a1/language-en

https://op.europa.eu/en/publication-detail/-/publication/aa273b09-c680-11e6-a6db-01aa75ed71a1/language-en/format-PDF/source-search

https://op.europa.eu/en/publication-detail/-/publication/14df524e-c81f-11e6-a6db-01aa75ed71a1/language-en/format-PDF/source-search

https://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/use-case-1/webapp/ -> a map with buildings and their energy performance level

The BSO includes more than 250 indicators grouped in 10 thematic areas: i.e., building stock characteristics, building renovation, nearly Zero-Energy Buildings, energy consumption, building shell performance, technical building systems, certification, financing, and energy poverty and energy market. (file:///C:/Users/popaa/Downloads/sustainability-12-00642-v2.pdf)

TODO

http://www.energimerking.no/no/Energimerking-Bygg/

* INFOREG: https://www.inforeg.sk/ec/SearchEC.aspx,sadlynoenergyconsumptiondatano onlyaddressandratinglevel.

MINETUR: Informe 3 (julio 2015) - Estado de la cer

www.statbel.fgov.be/ statistical information about dwellings, number of companies, etc.

www.ibgebim.be/ information about the energy consumption in the brussels region

www.vmm.be/ information about the energy consumption in the flanders region

www.vito.be/ information about the energy consumption in the flanders region

www.wallonie.be/ information about the energy consumption in the walloon region

mineco.fgov.be/ information about the energy consumption in belgium

www2.vlaanderen.be/ned/sites/economie/energiesparen/ information about the energy consumption in the flanders region

mineco.fgov.be/energy/rational_energy_use/report.pdf information and predictions of the energy savings potentials in belgium

www.odyssee-indicators.org/ information about the energy consumption in the EU countries (few information about belgium)

www.mina.vlaanderen.be/ information and comments on the climate plans of flanders

www.destatis.de/ Data of the German Statistical Office

www.statiskikbanken.dk Statistics Denmark makes statistics on Denmark in general. Some information is available free of charge.

www.ens.dk Danish Energy Agency makse statistics on energy comsumption on Denmark in general, including the building sector (not very detiled).

www.elsparefonden.dk Electricity savings trust - collects information about electricity savings and supports (on campain basis) use of electricity efficient appliances and transfer for electricity heating to district heating.

www.ebst.dk National Agency for Construction and Enterprice is responsible for making the Danish building code, including rules for energy comsumption in new buildings.

www.sbi.dk, Evaluation of the heating saving potential in existing dwellings, In Danish (Vurdering af potentialet for varmebesparelser i eksisterende boliger) By og Byg Documentation 057.

www.byg.dtu.dk Energy savings in existing and new dwellings, In Danish (Energibesparelser i eksisterende og nye boliger). BYG*DTU, 2004. R-080.

grbes.phys.uoa.gr not many things.most of the information is in greek

www.senternovem.nl/ Dutch Energy Agency: enormous source of all kinds of energy related studies

www.energie.nl/sts/index.html

www.energiened.nl umbrella organisation of energy companies in the Netherlands. Have good insight in energy consumption in The Netherlands for all sectors, both gas and electricity

statline.cbs.nl Central Bureau of Statistics: lots of statistical data, but not always in a format we would like www.vrom.nl Ministry of Housing: studies on building stock

www.ez.nl Ministry of Economical Affairs: responsible for various energy policies (e.g. emission trading, white certificates)

*https://invert.at/references.php no datasets found

* https://www.cso.ie/en/releasesandpublications/er/ndber/non-domesticbuildingenerg statistical graphs, like how many buildings per year have a certain rating

* www.enerfund.eu online map of countries, by zooming in and adding buildings to a list, they can be compared by Roamina: energy performance rating, C02 emission, total floor area. year of construction UK: energy performance rating, address, total floor area, window/roof/walls/energy efficiency (good/poor/average/very poor) IT: energy performance rating, address, total floor area No export functionalitity found, only pdf generation.

http://epcplus.org/

ESCO: kind of contractor agreement btw. tenant and owner in regard of retrofitting investments and renting costs.

A list of all asset programs for issuing energy certificates: https://bedes.lbl.gov/bedes-online/assessment-program

A list of glossary terms: https://www.buildingrating.org/glossary-terms

Some formulas for total DWH and other consumption (pg28-29): https://www.hotmaps-project.eu/wp-content/uploads/2018/03/D2.3-Hotmaps_for-upload_revised-final_.pdf

Climate zones EU28: pg 46

HotMaps Building stock Project: https://gitlab.com/hotmaps/building-stock

HotMaps Buildings stock data sources:https://gitlab.com/hotmaps/building-stock/-/tree/master/data

HotMaps solar radiation: https://gitlab.com/hotmaps/climate/climate_solar_radiation

The distribution of potential from solar radiation depends on the latitude of the country, as shown in Figure 53. Mediterranean provinces have higher potential than northern European countries. solar potential for some cities pg 121

nearly Zero-Energy Buildings (nZEB)

* Enerdata https://www.enerdata.net/user/register/

* European Data Portal https://data.europa.eu/euodp/en/data/ BELGUM: https://www.europeandataportal.eu/data/datasets/http-energiesparen-be-energieprestat locale=en

* https://epc.opendatacommunities.org/

Access to Energy Performance Certificates and Display Energy Certificates data for buildings in England and Wales Registration is needed, access token is in the uni webmail.

It will provide data to facilitate improvements in the energy efficiency of buildings through research, improved management and innovation. Royal Mail Group Limited permits the use of ‘address data’ for specific purposes related to the energy performance of buildings which are as follows: * [...] * Research into the effectiveness or impact of energy efficiency improvements including those delivered through Government or other energy improvement programmes.

In addition to the purposes set out above there are certain exceptions to copyright which permit you to use copyrighted material for specific and limited purposes. These include non-commercial research and private study, subject to compliance with certain conditions. Further information about these exceptions can be found here: https://www.gov.uk/guidance/exceptions-to-copyright.

All data fields other than the address and postcode data (address, address 1, address 2, address 3, postcode) available via this website are licensed under the Open Government Licence v3.0.

`https://epc.opendatacommunities.org/domestic/search` each EPC can be downloaded separatley as cvs file, also a recommendation csv file can be downloaded. API is available for programmatic searches of EPC data `https://epc.opendatacommunities.org/docs/api/domestic` some buildings might have more than one epc, not all have energy consumption data, but all have energy performance rating labels CVS data was downloaded at: `e:\docs\UniInnsbruck\Masterthesis\datasets\opendatacommunities\`

* REQUEST2ACTION 04/2014–08/2017

*Belgium's Retrofit Action Hub `http://genk.zetjewoningopdekaart.be/`

* Greece's Retrofit Action Hub `http://www.energyhubforall.eu/`

* Italy's Retrofit Action Hub `http://www.portale4e.it/`

* Portugal's Retrofit Action Hub Portal CasA+

* Scotland's (UK) Retrofit Action Hub `https://localhomesportal.est.org.uk/`

* ELISE datasets with epc data

`https://data.europa.eu/euodp/en/data/dataset/jrc-10124-10001`

`https://data.jrc.ec.europa.eu/dataset/jrc-10124-10001#__sid=js0`

UML diagram: `https://inspire-sandbox.jrc.ec.europa.eu/energy-pilot/use-case-1/data-models/uml-html-viewer/`

`https://publications.jrc.ec.europa.eu/repository/handle/JRC103868`

`https://publications.jrc.ec.europa.eu/repository/handle/JRC104587`

`https://joinup.ec.europa.eu/collection/elise-european-location-interoperability-s`
`energy-location-applications`

`https://epbd-ca.eu/wp-content/uploads/2019/08/CoCA-Factsheet-Wideruse-of-EPBD-dat`
`pdf`

* Slovenian building stock `https://egp.gu.gov.si/egp/?lang=en` datatset with buildingdata: address, floor size, room numbers.

* DATAMINE contains rating levels !!! `value_indicator1`

`http://www.meteo.noa.gr/datamine` publications Problem: database not available(?), there is a test database available but it has no rating level data :((((Institut Wohnen und Umwelt, Darmstadt - Germany – `www.iwu.de` 2008

* EXIST `http://www.enper-exist.com/pdf/reports/WP1\%20wd\%202\%20data\%20acquisition\%20final\%20report\%20echt\%20final.pdf` basic building data, no epc rating level TODO check links to statistical websites in the excel

* EPLabel Online (discontinued) `http://online.eplabel.org/` `https://ec.europa.eu/energy/intelligent/projects/en/projects/eplabel`

* klimaactive `https://klimaaktiv-gebaut.at/wohngebaeude.htm` eigenes Punktesystem e.g. 997 from 1000 points

* ZEUS

https://www.energieausweise.net/technische-spezifikation hilft dir einen EnergieasuweisErsteller in deiner Nähe zu finden.

https://www.immozeus.at/ueber-immo-zeus/ hilft den energieerstellern energieausweise zu berechnen, gilt für Bauunternehmer und EnergieAusweis Agenten ihre Energieausweise zu verwalten

https://episcope.eu/fileadmin/episcope/public/docs/pilot_actions/AT_EPISCOPE_RegionalCaseStudy_AEA.pdf

EPISCOPE: Die ZEUS-Datenbank verfügt über eine technische Schnittstelle, über die Energieausweisdaten aus Energieausweisberechnungsprogrammen, die am österreichischen Markt verfügbar sind, in die Datenbank übertragen werden können. Über ein offenes XML-Format2 werden pro Gebäude in Abhängigkeit von Typologie und Beschaffenheit im Schnitt 400 Datenfelder gespeichert, die die Gebäudehülle (vorhandene Aufbauten), das Haustechniksystem und die im Energieausweis berechneten Energiekennzahlen beschreiben und auswertbar machen

Diese zwei Basisparameter bilden auch die zwei Achsen der Matrix der Gebäudetypologie und ergeben eine Grundtypologie von 32 Modellgebäuden. Für jeden Gebäudetyp wurde ein Gebäude ausgesucht, das repräsentativ für alle Gebäude dieser Klasse steht. Als „repräsentativ" gelten die Gebäude hinsichtlich der UWerte, der Brutto-Grundfläche, ihres Heizwärmebedarfs (HWB) sowie des Raumheizungs- und Warmwassersystems. Dafür wurden reale Gebäude, deren Energieausweise nach der OIB-RL 6 berechnet wurden, aus der Energieausweisdatenbank ZEUS ausgewählt.

5.3.1 Aufbau der Gebäudetypologie (TABULA/EPISCOPE) Die Österreichische Gebäudetypologie (TABULA/EPISCOPE) definiert verschiedene Modellgebäude, die bestimmte Gebäudekategorien in unterschiedlichen Baualtersklassen repräsentieren:

Baualtersklassen:
* I vor 1919
* II 1919–44
* III 1945–59
* IV 1960–79
* V 1980–89
* VI 1990–99
* VII 2000–20
* VIII >2020

Gebäudekategorie:
* EFH: Einfamilienhäuser (1 - 2 Wohneinheiten)
* RH: Reihenhäuser
* MFH: Mehrfamilienhäuser (3 - 10 Wohneinheiten)
* MWB: Mehrgeschossige, großvolumige Wohnbauten (ab 11 Wohneinheiten)

„GECKO" Salzburg * Statistik Austria

JoinUp

BuildUp EU

https://joinup.ec.europa.eu/sites/default/files/document/2015-10/location_data_for_buildings_related_energy_efficiency_policies_-_feasibility_study_v13_-_annexes.pdf

One example is the Irish Building Energy Rating database (http://www.buildup.eu/blog/34657) containing energy ratings (for EPBD) for over 300,000 dwellings. The Sustainable Energy Authority of Ireland (SEAI) provided a public view of this database, freely accessible8 This database provides a detailed view of a large number of new and existing Irish dwellings, with data available for download in CSV/XLS format. The whole dataset is about 480,000 records, at building unit level, and more than 130 properties (e.g. Dwelling Type, Year of construction, Energy Rating, GroundFloorArea(sq m), UValue Wall, UValue Roof, UValue Window, Uvalue Door, Wall Area, Roof Area, Floor Area, Window Area, Door Area, Number of Storeys, CO2 Rating, Main Space Heating Fuel, Main Water Heating Fuel, HS Main System Efficiency, WH Renewable Resources, Number Of Chimneys, Structure Type, Temp. Adjustment, Heating System Control, ...)

*Ireland government

https://ndber.seai.ie/BERResearchTool/Register/Register.aspx https://ndber.seai.ie/BERResearchTool/ber Rating Level C1, C2, D1 ...

e:\docs\UniInnsbruck\Masterthesis\datasets\IRELANDBER\BERPublicSearch\

* Scottisch Gouvernment !!!!! e:\docs\UniInnsbruck\Masterthesis\datasets\Scottland\

YEAY DATA with EPC and also potential EPC zip, api, sparql endpoint: https://statistics.gov.scot/data/domestic-energy-performance-certificates web ui: https://www.scottishepcregister.org.uk/CustomerFacingPortal/TermsAndConditions

https://statistics.gov.scot/data/domestic-energy-performance-certificates

*Portugal https://www.sce.pt/pesquisa-certificados/ suche nach epc, es sind aber keine Verbrauchsdaten vorhandem nur Adresse und Rating Level

*https://www.mdpi.com/2071-1050/12/2/642/htm

**Eurostat

- is an official directorate-general of the European Commission (EC) with the main responsibility to provide statistical information to the institutions of the European Union. The statistics are open data available on its website.

- The database of Eurostat contains always the latest version of the datasets meaning that there is no versioning on the data. Datasets are updated twice a day, at 11:00 and at 23:00, in case new data are available or because of structural change. It is possible to access the datasets through SDMX Web Services as well as Json and Unicode Web Services

https://ec.europa.eu/eurostat/web/energy/data/database statistics like heating and cooling days per year per country, energy consumption per country. nr of dwelling per type per country per year https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=cens_01ndbuild&lang=en

*ExcEED

09/2016–09/2019

enbuibench platform http://www.exceedproject.eu/register-to-the-platform/

Databases are not open-source, it is not possible to do query by external users. It is possible to see only aggregated and anonymous data through the geocluster tool. The rough data of each building can be visualized only by the owner.

As seen in section ?? the ExcEED[4] database and platform was developed and funded during the HORIZON 2020 project.

Some other Tools and Platforms

- ZEBRA2020 DataTool: renovation, energy efficiency trends;http://www.zebra-monitoring.enerdata.eu/ CLimate zone distribution http://www.zebra-monitoring.enerdata.eu/nzeb-activities/panel-distribution.html Heating demand per zone: http://www.zebra-monitoring.enerdata.eu/nzeb-activities/panel-distribution.html
- CommONEnergyEconomic Assessment Tool
- ComONEnergy Data Mapper & Scenario Tool
- ENTRANZE DataTool: energy systems, building characteristics thermal quality, ownership
- Building Rating; FRONT consumer tools: decision making tool
- ENERGYFUND tool
- GBPN Policy Comparative Tool
- IEA Policies and Measures; BEEP Database;
- REEGLE Database
- HotMaps https://www.hotmaps-project.eu/how-to-use/ graphical data

ODYSEE-MURE Database;

http://www.measures-odyssee-mure.eu/ Seems to be a database with pdfs (legislation documents)

https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html maybe you find some data there

https://odyssee.enerdata.net/database/ login data in email. Total sums per country and year.

TODO: play around with some datasets, try out different methods

TODO: attention to measuring unit differences

Distribution of renewable energy https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_executive_summary.pdf images/distribution_of_renewable_ernergy.png

Energy consumption per country (statistical data):

http://www.entranze.enerdata.eu/#/share-of-space-heating-in-total-residential-con
html

Austria

- Austrian Statistics

[4] http://www.exceedproject.eu/

- IEE-Project RES-H Policy (Policy development for improving Renewable Energy Sources Heating & Cooling Penetration in European Member States)

- Müller, A., Kranzl, L. Energieszenarien bis 2030: Wärmebedarf der Kleinverbraucher. Ein Projekt im Rahmen der Erstellung von energiewirtschaftlichen Inputparametern und Szenarien zur Erfüllung der Berichtspflichten des Monitoring Mechanisms. Wien, April 2013.

Belgium

- Statistics Belgium

Bulgaria

- National Statistical Institute (NSI)
- SOFENA

Croatia

- Croatian Bureau of Statistics

Cyprus

- Statistical Service (CY-STAT)

Czech Rep.

- Czech Statistical Office
- Panel SCAN
- Seven

Denmark

- CECODHAS Housing Europe
- Statistics Denmark

Estonia

- Statistical Office of Estonia

Finland

- Source Heat Pump (ASHP)
- Statistics Finland

France

- French Ministry of Energy , Environment and Sustainable Development-MEEDDM
- INSEE- French National Statistics Institute

Germany

- Federal Statistics Office (Destatis)
- Fraunhofer Institute for Systems and Innovation Research ISI
- Institut Wohnen und Umwelt GmbH (IWU)

Greece

- Hellenic Statistical Authority (El.Stat)
- IEE-Project RES-H Policy (Policy development for improving Renewable Energy Sources Heating & Cooling Penetration in European Member States)

Hungary

- Hungarian Central Statistical Office (KSH)

Ireland

- Central Statistics Office Ireland (CSO)
- Sustainable Energy Authority of Ireland (SEAI)

Italy

- Italian National agency for new technologies, Energy and sustainable economic (ENEA)
- National Institute for Statistics (ISTAT)
Latvia
- Central Statistical Bureau of Latvia
Lithuania
- IEE-Project RES-H Policy (Policy development for improving Renewable Energy Sources Heating & Cooling Penetration in European Member States)
- State Enterprise Centre of Registers
- Statistics Lithuania
Luxembourg
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Malta
- Misiukaite
- National Statistics Office (NSO)
Netherlands
- IEE-Project RES-H Policy (Policy development for improving Renewable Energy Sources Heating & Cooling Penetration in European Member States)
- Statistic Netherlands (CBS)
Poland
- Central Statistic Offices
Portugal
- National Statistics Institute (INE)
Romania
- EuroHeat&Power
Serbia
- Dr Slobodan Ruzic, Energy Saving Group ltd .Belgrade, Serbia
- National Statistics of Serbia
Slovakia
- Green Investment Scheme
- SEVEN
- Slovak building standards
Slovenia
- SI-STAT
- Slovak National statistics
Spain
- Ministry of Public Works
- National Statistics Institute (INE)
Sweden
- CECODHAS Housing Europe

- Sweden statistics

UK

- IEE-Project RES-H Policy (Policy development for improving Renewable Energy Sources Heating & Cooling Penetration in European Member States)

Preparation of data

From the paper "towards energy efficiency smart building models based on intelligent data analytics". [33]

1. Cleaning and transformation:

- selecting predictive variables
- deleting energy consumption outliers that cannot be related to outliers in the rest of the variables
- transforming categorical into numerical variables
- dividing the set of data into train (75%) and test (25%)

2. Standarization: transform the variables to have zero mean and unit standard deviation.

3. A common technique applied to data is the transformation of the data space using the so called Principal Components Analysis (PCA)15. PCA is a widely used technique for reducing dimensionality, identifying the directions in which the variance of the observations is accumulated.

4. Validation method: 10-fold cross validation and 5 repetitions over the training data set.

Chapter 4

Implementation

Combining the data analytics/machine learning with semantics (semantic technologies) e.g. making the data sets and usage explainable to the users -> Explainable AI

4.1 Application

4.1.1 Data Import

maybe move the data-import to another chapter

For the basis of the recommender system we looked for datasets that include energy performance data. Of particular interest were datasets with epc ratings and energy consumption measures. There were quite some open datasets available online with building energy consumption data, but fewer included epc rating data.

We settled on governmental open datasets from France[1], Scottland[2], England[3] and Ireland [4]. These datasets are offered as .csv data files. This files have a variety of fields, but only the ones that are relevant were extracted and imported into the application's database. In order to accomplish this, a custom CSV-Importer written in the Java programming language was developed. The importer takes each .cvs file containing raw data and imports the required fields into the database as an .json formatted data entry (json objects). The database is a NoSQL MongoDB database hosted on the MongoDB Cloud platform[5].

4.1.2 Application Architecture

The application developed for this thesis contains two modules, a user interface and a REST API. For the end user, the user interface is of interest, but for third party applications the REST API is accessible on demand.

[1] https://www.europeandataportal.eu/data/datasets/diagnostics-de-performance-energetique-pour-les-logements?locale=en

[2] https://statistics.gov.scot/data/domestic-energy-performance-certificates

[3] https://epc.opendatacommunities.org/

[4] https://ndber.seai.ie/BERResearchTool/Register/Register.aspx

[5] https://www.mongodb.com/cloud/atlas

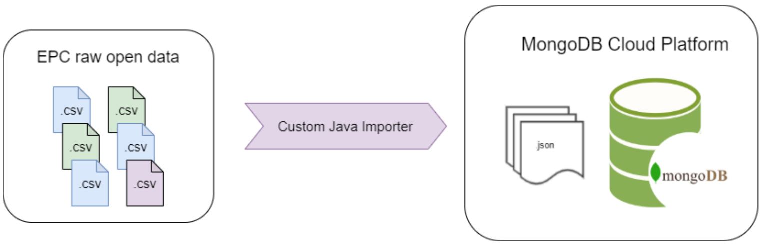


Figure 4.1: Data import

For example, the user calls the UI application and selects a country.

change this example

. The user receives a nicely displayed json result.

give example with screenshot

In case a third party application wants to access the data, it can call the REST API directly and receives a json formatted file without the presentation styles offered for users in the user interface.

give example with screenshot

The User Interface was developed using the JavaScript library ReactJS[6] and is deployed on a Node.js[7] server hosted on the heroku[8] platform. The REST API is implemented as a Java application running on a Tomcat 9 server, which is also hosted on the heroku platform.

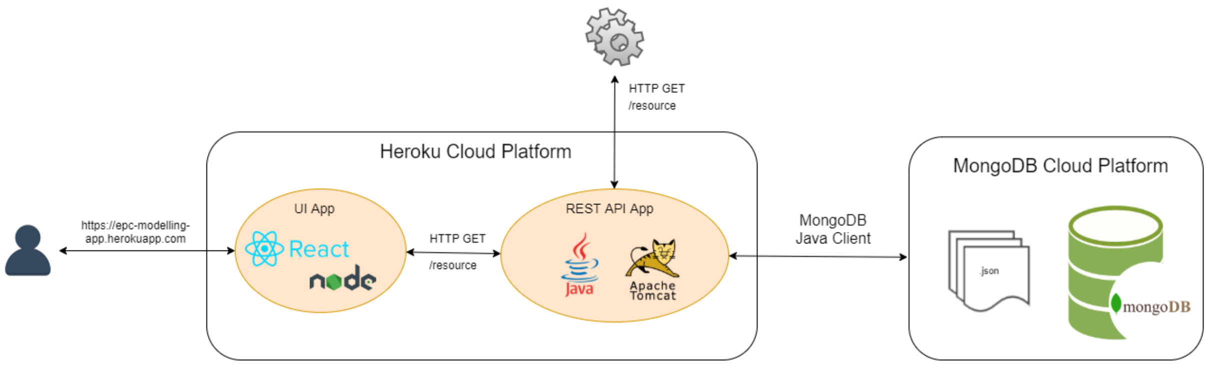


Figure 4.2: Application Architecture

The UI is accessible at `https://epc-modelling-app.herokuapp.com/`.

The REST API is accessible at `https://epc-modelling-backend.herokuapp.com/`.

present all REST API calls

[6]https://reactjs.org/
[7]https://nodejs.org/en/about/
[8]https://dashboard.heroku.com/

Chapter 5

Results

The results show that this method is more accurate than the certification mechanisms done until now.

Chapter 6

Conclusion

6.1 Conclusion

By using the near-zero energy building concept and implementing renewable energy in buildings we are able to better understand the behaviour of buildings.

This thesis aimed at finding a solution for reducing the demand for primary energy (heating, domestic hot water and electric energy consumption) by analysing possible renewable sources (e.g. solar systems). This work resulted in the creation of an application (recommender system/decision making system). Models for data-driven energy classification of buildings were presented. This models might fit or not to the classification given by manual assessments. We believe that data-driven classification is an accurate and non-subjective classification in comparison with the manual (human-driven) classification.

IHDs (Inteligent Home Displays) are not smart enough to address building context or personal motivations.[55]

According to [45] governments should:

- Require all new buildings, as well as buildings undergoing renovation, to meet energy codes and minimum energy performance standards.
- Support and encourage the construction of buildings with net-zero energy consumption.
- Implement policies to improve the energy efficiency of existing buildings.
- Require building energy performance labels or certificates that provide information to owners, buyers and renters.

In order to avoid fuel poverty, the comfort of the users should not be compromised in the desire of lowering the carbon footprint of buildings[34].

6.2 Future Work

Energy efficiency should be applied on the whole energy production and consumption chain, not only on the energy consumption of buildings. The EU Project "Heat

Roadmap Europe"[1] estimates that there is heat wasted during electricity generation in Europe, that is required to head all buildings on our continent.

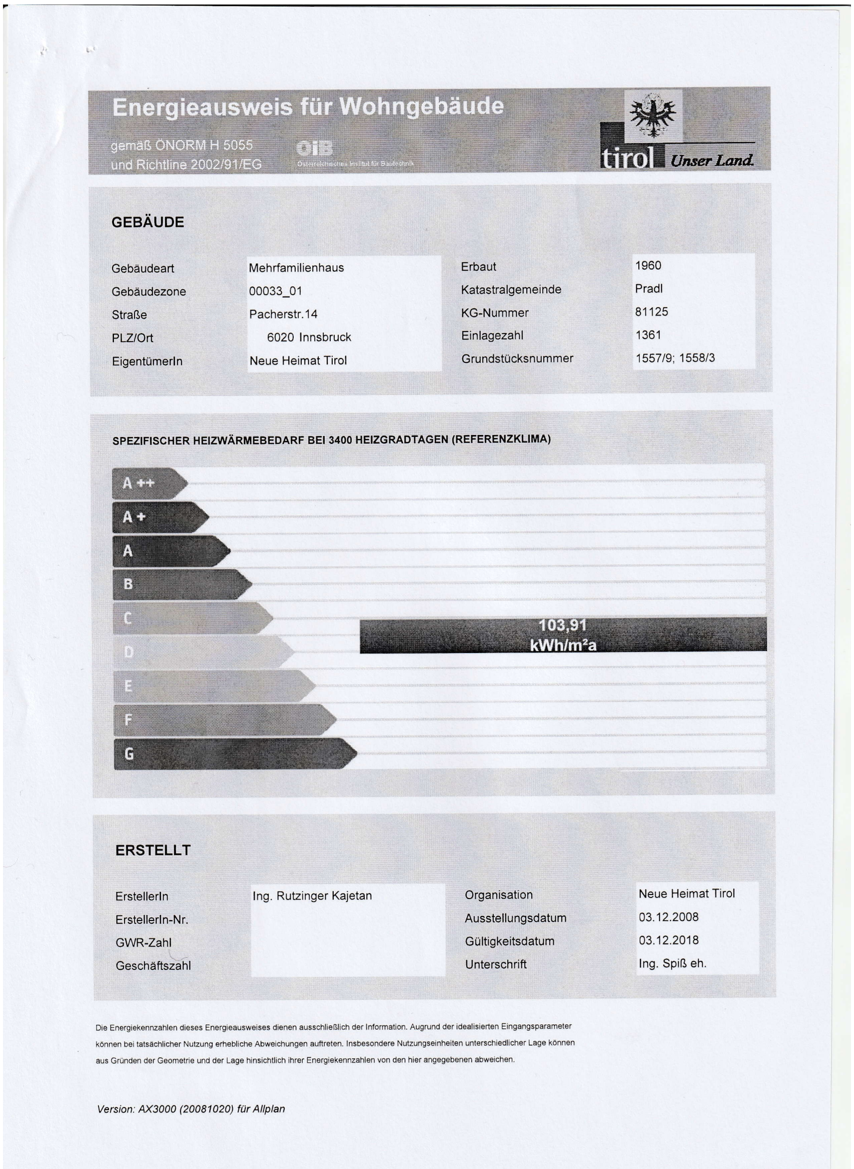
add some ideas for future work, after finalising the implementation

[1] heatroadmap.eu

Appendix A

Austrian Energy Certificate

Source: personal archive



Energieausweis für Wohngebäude

gemäß ÖNORM H 5055
und Richtlinie 2002/91/EG

tirol Unser Land.

GEBÄUDE

Gebäudeart	Mehrfamilienhaus	Erbaut	1960
Gebäudezone	00033_01	Katastralgemeinde	Pradl
Straße	Pacherstr.14	KG-Nummer	81125
PLZ/Ort	6020 Innsbruck	Einlagezahl	1361
EigentümerIn	Neue Heimat Tirol	Grundstücksnummer	1557/9; 1558/3

SPEZIFISCHER HEIZWÄRMEBEDARF BEI 3400 HEIZGRADTAGEN (REFERENZKLIMA)

A ++
A +
A
B
C
D
E
F
G

103,91 kWh/m²a

ERSTELLT

ErstellerIn	Ing. Rutzinger Kajetan	Organisation	Neue Heimat Tirol
ErstellerIn-Nr.		Ausstellungsdatum	03.12.2008
GWR-Zahl		Gültigkeitsdatum	03.12.2018
Geschäftszahl		Unterschrift	Ing. Spiß eh.

Die Energiekennzahlen dieses Energieausweises dienen ausschließlich der Information. Augrund der idealisierten Eingangsparameter können bei tatsächlicher Nutzung erhebliche Abweichungen auftreten. Insbesondere Nutzungseinheiten unterschiedlicher Lage können aus Gründen der Geometrie und der Lage hinsichtlich ihrer Energiekennzahlen von den hier angegebenen abweichen.

Version: AX3000 (20081020) für Allplan

Energieausweis für Wohngebäude

gemäß ÖNORM H 5055
und Richtline 2002/91/EG

OIB Österreichisches Institut für Bautechnik

tirol Unser Land.

GEBÄUDEDATEN

Brutto-Grundfläche	800,86 m²
beheiztes Brutto-Volumen	2272,87 m³
charakteristische Länge (lc)	1,99 m
Kompaktheit (A/V)	0,5035 1/m
mittlerer U-Wert (Um)	0,90 W/m²K
LEK-Wert	67

KLIMADATEN

Klimaregion	NF
Seehöhe	573 m
Heizgradtage	3704,0 Kd
Heiztage	220,0 d
Norm-Außentemperatur	-11,4 °C
Soll-Innentemperatur	20,0 °C

WÄRME- UND ENERGIEBEDARF

	Referenzklima		Standortklima		Anforderung
	zonenbezogen		zonenbezogen	spezifisch	
HWB	83.216,46 kWh/a	103,91 kWh/m²a	98.806,88 kWh/a	123,38 kWh/m²a	52,18 kWh/m²a nicht erfüllt
WWWB			10.230,99 kWh/a	12,78 kWh/m²a	
HTEB-RH			27.347,42 kWh/a	34,15 kWh/m²a	
HTEB-WW			8.147,47 kWh/a	10,17 kWh/m²a	
HTEB			35.494,88 kWh/a	44,32 kWh/m²a	
HEB			145.344,73 kWh/a	181,49 kWh/m²a	
EEB			145.344,73 kWh/a	181,49 kWh/m²a	144,05 kWh/m²a nicht erfüllt
PEB					
CO_2					

ERLÄUTERUNGEN

Heizwärmebedarf (HWB)	Vom Heizsystem in die Räume abgegebene Wärmemenge, die benötigt wird, um während der Heizsaison bei einer standardisierten Nutzung eine Temperatur von 20°C zu halten.
Heiztechnikenergiebedarf (HTEB):	Energiemenge, die bei der Wärmeerzeugung und -verteilung verloren geht
Endenergiebedarf (EEB):	Energiemenge, die dem Energiesystem des Gebäudes für Heizung und Warmwasserversorgung inklusive notwendiger Energiemengen für die Hilfsbetriebe bei einer typischen Standardnutzung zugeführt werden muss.

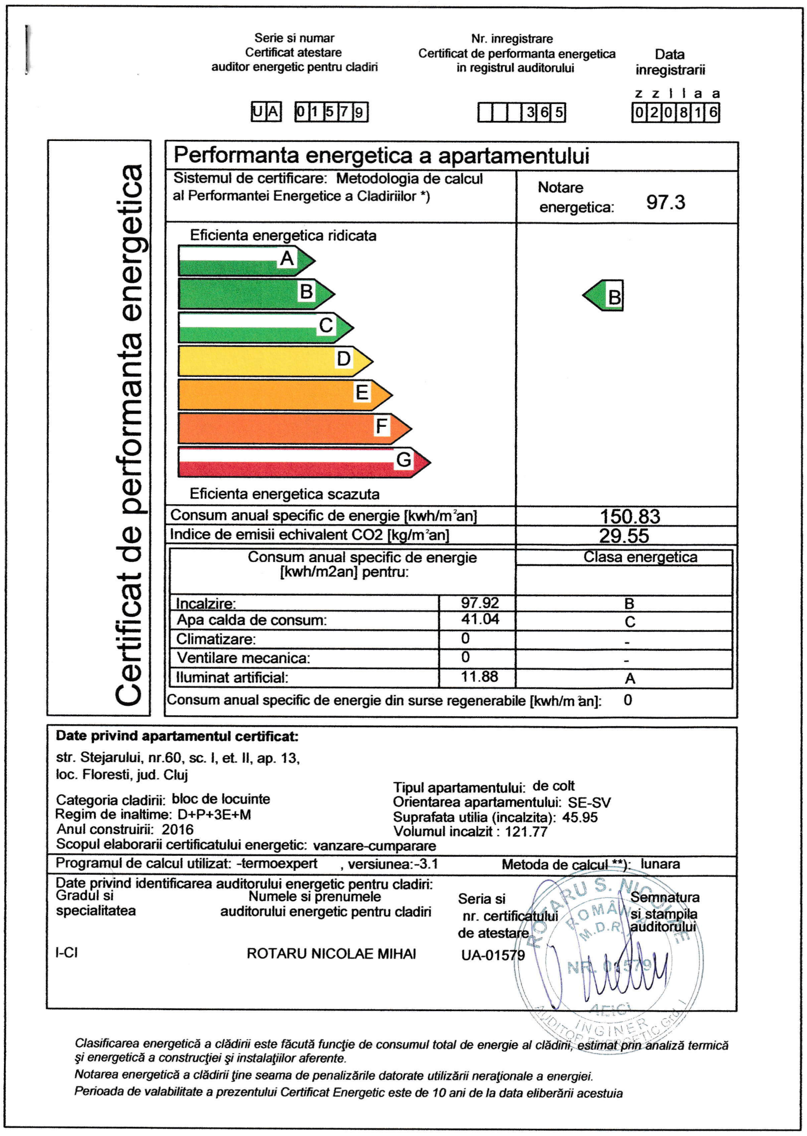
Die Energiekennzahlten dieses Energieausweises dienen ausschließlich der Information. Augrund der idealisierten Eingangsparameter können bei tatsächlicher Nutzung erhebliche Abweichungen auftreten. Insbesondere Nutzungseinheiten unterschiedlicher Lage können aus Gründen der Geometrie und der Lage hinsichtlich ihrer Energiekennzahlen von den hier angegebenen abweichen.

Version: AX3000 (20081020) für Allplan

Appendix B

Romanian Energy Certificate

Source: personal archive



Serie si numar Certificat atestare auditor energetic pentru cladiri: UA 01579

Nr. inregistrare Certificat de performanta energetica in registrul auditorului: 365

Data inregistrarii (z z l l a a): 020816

Certificat de performanta energetica

Performanta energetica a apartamentului

Sistemul de certificare: Metodologia de calcul al Performantei Energetice a Cladiriilor *)

Notare energetica: 97.3

Eficienta energetica ridicata

A B C D E F G

Eficienta energetica scazuta

B

Consum anual specific de energie [kwh/m²an]	150.83
Indice de emisii echivalent CO2 [kg/m²an]	29.55

Consum anual specific de energie [kwh/m2an] pentru:		Clasa energetica
Incalzire:	97.92	B
Apa calda de consum:	41.04	C
Climatizare:	0	-
Ventilare mecanica:	0	-
Iluminat artificial:	11.88	A

Consum anual specific de energie din surse regenerabile [kwh/m²an]: 0

Date privind apartamentul certificat:

str. Stejarului, nr.60, sc. I, et. II, ap. 13,
loc. Floresti, jud. Cluj

Categoria cladirii: bloc de locuinte
Regim de inaltime: D+P+3E+M
Anul construirii: 2016

Tipul apartamentului: de colt
Orientarea apartamentului: SE-SV
Suprafata utilia (incalzita): 45.95
Volumul incalzit : 121.77

Scopul elaborarii certificatului energetic: vanzare-cumparare

Programul de calcul utilizat: -termoexpert , versiunea:-3.1 Metoda de calcul **): lunara

Date privind identificarea auditorului energetic pentru cladiri:

Gradul si specialitatea	Numele si prenumele auditorului energetic pentru cladiri	Seria si nr. certificatului de atestare	Semnatura si stampila auditorului
I-CI	ROTARU NICOLAE MIHAI	UA-01579	

ROTARU S. NICOLAE MIHAI ROMÂNIA M.D.R. NR. 01579 AEIC INGINER AUDITOR ENERGETIC Gr. I

Clasificarea energetică a clădirii este făcută funcţie de consumul total de energie al clădirii, estimat prin analiză termică şi energetică a construcţiei şi instalaţiilor aferente.

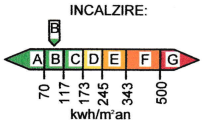
Notarea energetică a clădirii ţine seama de penalizările datorate utilizării neraţionale a energiei.

Perioada de valabilitate a prezentului Certificat Energetic este de 10 ani de la data eliberării acestuia

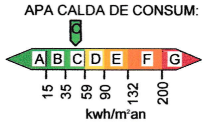
DATE PRIVIND EVALUAREA PERFORMANTEI ENERGETICE A APARTAMENTULUI

- Grile de clasificare energetica functie de consumul de caldura anual specific:

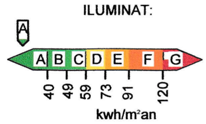
INCALZIRE:



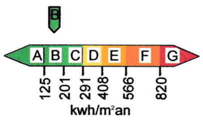
APA CALDA DE CONSUM:



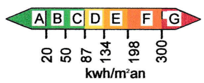
ILUMINAT:



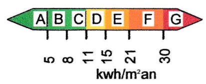
TOTAL:
Incalzire, apa calda de consum, iluminat



CLIMATIZARE:



VENTILARE MECANICA:



- Penalizari aplicate apartamentului si motivarea acestora:

P0 = 1 dupa cum urmeaza:

- Corpurile statice sunt dotate cu armaturi de reglaj si acestea sunt functionale	-1
- Corpurile statice au fost demontate si spalate / curatate in totalitate dupa ultimul sezon de incalzire	-1
- Coloanele de incalzire sunt prevazute cu armaturi de separare si golire a acestora, functionale	-1
- Exista contor general de caldura pentru incalzire si pentru apa calda menajera	-1
- Stare buna a tencuielii exterioare	-1
- Pereti exteriori uscati	-1
- Acoperis etans	-1
- Cosurile au fost curatate cel putin o data in ultimii doi ani	-1
- Cladire prevazuta cu sistem de ventilare naturala organizata sau ventilare mecanica	-1
- Stare tehnica buna	-1

Clasificarea energetică a clădirii este făcută funcţie de consumul total de energie al clădirii, estimat prin analiză termică şi energetică a construcţiei şi instalaţiilor aferente.
Notarea energetică a clădirii ţine seama de penalizările datorate utilizării neraţionale a energiei.
Perioada de valabilitate a prezentului Certificat Energetic este de 10 ani de la data eliberării acestuia

Appendix C

Danish Energy Certificate

Source:
https://docplayer.dk/18645796-Energimaerke-adresse-dr-lassens-gade-7-postnr-by.html

Energimærkning

SIDE 1 AF 9

Energimærkning for følgende ejendom:

Adresse:	Dr. Lassens Gade 7
Postnr./by:	8900 Randers C
BBR-nr.:	730-009955-001
Energimærkning nr.:	200038127
Gyldigt 5 år fra:	29-09-2010
Energikonsulent:	Jan Ole Hansen
Programversion:	Energy08, Be06 version 4
Firma:	Ingeniørfirmaet Henrik Møgelgaard ApS

Energimærkningen oplyser om ejendommens energiforbrug, mulighederne for at opnå besparelser, fordeling af ejendommens varmeudgifter samt de enkelte lejligheders gennemsnitlige forbrug. Mærkningen er lovpligtig og skal udføres af et certificeret firma eller en beskikket energikonsulent, som har godkendelse til at energimærke flerfamiliehuse.

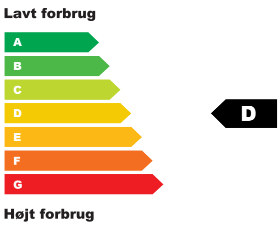
Oplyst varmeforbrug

- **Udgift inkl. moms og afgifter:** 76.091 kr./år
- **Forbrug:** 109.509 kWh fjernvarme
- **Oplyst for perioden:**

Fjernvarme: 01-03-2008 - 28-02-2009

Ejendommens oplyste forbrug og udgifter er klimakorrigerede af energikonsulenten, så det udtrykker forbrug og udgifter for et gennemsnitligt år rent temperaturmæssigt.

Energimærke



Besparelsesforslag

Energikonsulenten foreslår forbedringerne nedenfor. Der kan være flere forslag på side 2.
Se mere om forslagene i afsnittet "Energikonsulentens bygningsgennemgang".

	Forslag til forbedring	Årlig besparelse i energienheder	Årlig besparelse i kr. inkl. moms	Skønnet investering inkl.moms	Tilbage-betalingstid
1	Isolering af etageadskillelse mod uopvarmet kælder	9 kWh el 7.770 kWh fjernvarme	4.800 kr.	56.100 kr.	11,8 år
2	Isolering af etageadskillelse mod uopvarmet loftrum	9 kWh el 7.770 kWh fjernvarme	4.800 kr.	56.100 kr.	11,8 år
3	Efterisolering af varmefordelingsrør	-3 kWh el 3.880 kWh fjernvarme	2.400 kr.	9.900 kr.	4,2 år
4	Montering af ny cirkulationspumpe på varmeanlæg	422 kWh el	900 kr.	4.500 kr.	5,3 år

Appendix D

German Energy Certificate

Source: GermanEPC:2016 TODO: include all pages ?? add year of Vorlage

ENERGIEAUSWEIS für Wohngebäude

gemäß den §§ 16 ff. Energieeinsparverordnung (EnEV) vom [1] 18.11.2013

Gültig bis: 23.06.2024 **Registriernummer [2]:** 123456789 **1**

Gebäude

Gebäudetyp	Mehrfamilienhaus
Adresse	Musterstr. 123, 10115 Musterstadt
Gebäudeteil	Vorderhaus
Baujahr Gebäude [3]	1927
Baujahr Wärmeerzeuger [3][4]	1982
Anzahl Wohnungen	9
Gebäudenutzfläche (A_N)	546 m² ☐ nach § 19 EnEV aus der Wohnfläche ermittelt
Wesentliche Energieträger für Heizung und Warmwasser [3]	Erdgas H
Erneuerbare Energien	Art: keine Verwendung: keine
Art der Lüftung / Kühlung	☑ Fensterlüftung ☐ Schachtlüftung ☐ Lüftungsanlage mit Wärmerückgewinnung ☐ Lüftungsanlage ohne Wärmerückgewinnung ☐ Anlage zur Kühlung
Anlass der Ausstellung des Energieausweises	☐ Neubau ☑ Vermietung / Verkauf ☐ Modernisierung (Änderung / Erweiterung) ☐ Sonstiges (freiwillig)

Hinweise zu den Angaben über die energetische Qualität des Gebäudes

Die energetische Qualität eines Gebäudes kann durch die Berechnung des **Energiebedarfs** unter Annahme von standardisierten Randbedingungen oder durch die Auswertung des **Energieverbrauchs** ermittelt werden. Als Bezugsfläche dient die energetische Gebäudenutzfläche nach der EnEV, die sich in der Regel von den allgemeinen Wohnflächenangaben unterscheidet. Die angegebenen Vergleichswerte sollen überschlägige Vergleiche ermöglichen **(Erläuterungen – siehe Seite 5).** Teil des Energieausweises sind die Modernisierungsempfehlungen (Seite 4).

☑ Der Energieausweis wurde auf der Grundlage von Berechnungen des **Energiebedarfs** erstellt (Energiebedarfsausweis). Die Ergebnisse sind auf **Seite 2** dargestellt. Zusätzliche Informationen zum Verbrauch sind freiwillig.

☑ Der Energieausweis wurde auf der Grundlage von Auswertungen des **Energieverbrauchs** erstellt (Energieverbrauchsausweis). Die Ergebnisse sind auf **Seite 3** dargestellt.

Datenerhebung Bedarf / Verbrauch durch: ☐ Eigentümer ☑ Aussteller

☐ Dem Energieausweis sind zusätzliche Informationen zur energetischen Qualität beigefügt (freiwillige Angabe).

Hinweise zur Verwendung des Energieausweises

Der Energieausweis dient lediglich der Information. Die Angaben im Energieausweis beziehen sich auf das gesamte Wohngebäude oder den oben bezeichneten Gebäudeteil. Der Energieausweis ist lediglich dafür gedacht, einen überschlägigen Vergleich von Gebäuden zu ermöglichen.

Aussteller
Paul Mustermann
Musterstraße 45
12345 Musterstadt

24.06.2014 — P. Mustermann

Datum — Unterschrift des Ausstellers

1) Datum der angewendeten EnEV, gegebenenfalls angewendeten Änderungsverordnung zur EnEV 2) Bei nicht rechtzeitiger Zuteilung der Registriernummer (§ 17 Absatz 4 Satz 4 und 5 EnEV) ist das Datum der Antragstellung einzutragen; die Registriernummer ist nach deren Eingang nachträglich einzusetzen. 3) Mehrfachangaben möglich 4) bei Wärmenetzen Baujahr der Übergabestation

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