UNIVERSIDADE DE TRÁS-OS-MONTES E ALTO DOURO

Energy-Efficient Techniques Applied in Rehabilitation

Master Thesis in Civil Engineering

Marina de Almeida Batista

Supervisor: Anabela Gonçalves Correia de Paiva

Co supervisor: Jorge Tiago Queirós da Silva Pinto

Vila Real, 2020

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RESUMO

A reabilitação de edifícios provou ser uma possibilidade sustentável para edifícios que não atendem às necessidades de conforto exigidas pelos seus utilizadores. Como resultado, nos últimos anos, ações de reforma têm sido cada vez mais adotadas, por quem não só quer modernizar os edifícios, mas também manter a estética e a história do edifício.

É notório que os edifícios antigos devido à falta de manutenção e ao abandono, se foram tornando obsoletos em diferentes aspetos, que poderiam atender às exigências relevantes de sustentabilidade e conforto. Entretanto, um projeto de reabilitação bem projetado, se executado corretamente, pode tornar os edifícios mais sustentáveis, bem como mais eficientes em termos energéticos.

As soluções de eficiência energética são inúmeras. Entretanto, é necessário realizar um estudo para encontrar o resultado mais adequado para o projeto de reabilitação específico. Um ponto essencial a ser considerado diz respeito à localização do edifício. As diferentes zonas climáticas exigem soluções diferentes a serem seguidas. Isto deve-se ao facto de que a temperatura, a humidade, a posição do sol, entre outras, são variáveis com influência direta na demanda de energia e conforto.

Os países estão procurando cada vez mais incentivar a reabilitação dos edifícios existentes para torná-los mais eficientes em termos energéticos e, até mesmo elevá-los aos padrões NZEB (edifícios com energia quase zero), uma proposta mais ambiciosa que já é obrigatória em países da União Europeia. Assim, cada governo propõe na sua legislação valores-limite para o desempenho energético dos edifícios, que uma vez respeitados, recebem a certificação energética correspondente.

Neste trabalho, são analisados três edifícios a serem reabilitados que estão localizados em diferentes países e zonas climáticas. A ideia é, através de cálculos da carga de aquecimento e refrigeração, identificar os elementos com maior influência sobre a eficiência energética do edifício. Assim, serão propostas soluções que se encaixem nos valores impostos pelos sistemas de certificação energética e legislação utilizadas em cada um dos países, a fim de tornar os edifícios energeticamente mais eficientes.

Neste contexto, nesta dissertação é realizada uma análise comparativa das legislações e sistemas de certificação energética propostas por cada país em estudo, a fim de identificar se estas leis e certificados previstos são adequados ou se podem ser melhorados.

PLAVRAS-CHAVE: Reabilitação, Eficiência Energética, Certificação Energética, Desempenho Energético, NZEB.

ABSTRACT

Building rehabilitation has proven to be a sustainable possibility for buildings that no longer meet the comfort needs demanded by their users. As a result, in recent years, refurbishment actions have been increasingly adopted by individuals who not only want to modernize their buildings, but also want to maintain the aesthetics and history of their building.

It is notorious that old buildings have not evolved with new technologies and were not well maintained, making them obsolete on different issues that could make them more sustainable and comfortable. However, a well-designed and straightforward rehabilitation project, if executed properly, can make them sustainable, as well as energy efficient.

The energy efficient solutions are numerous. However, it is necessary to carry out a study to find the most suitable output for a specific rehabilitation project. An essential point to be considered refers to the location of the building. Different climate zones require different solutions to be implemented. This is due to the fact that temperature, humidity, position of the sun, among others, are variables with a direct influence on energy demand and comfort.

Countries are increasingly seeking to encourage the rehabilitation of existing buildings to make them energy efficient, and even bring them up to NZEB (near-zero energy buildings) standards, a more ambitious proposal that is already mandatory in European Union countries. Thus, each government proposes in its legislation limit values for the energy performance of buildings, which once respected, receive the corresponding energy certification.

In this thesis, three buildings to be rehabilitated, that are located in different countries and climate zones, are analysed. The idea is, through calculations of the heating load and cooling load, to identify the elements with the greatest influence on the building's energy efficiency. Thus, solutions will be proposed to meet the requirements of the energy certification system and legislation used in each country, in order to make buildings energy efficient.

In this context, this thesis will carry out a comparative analysis of the energy certification systems implemented by each country under study, in order to identify whether the proposed designs are according to the standards or if they should be improved.

KEYWORDS: Rehabilitation, Energy Efficient, Energy Certification, Energy Performance, NZEB.

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Chapter 1

Introduction

1. INTRODUCTION

1.1 Framework

Human beings are depleting the planet's natural resources, and levels of quality of life will begin to decline around 2030 if immediate action is not taken. The World Wide Fund for Nature warns that the current over-exploitation of natural resources is creating a huge deficit. Every year, 20% more resources are consumed in relation to the amount regenerated, and this percentage does not stop growing (WWF, 2016).

In this context, the consumption of energy and natural resources has been increasing with the development and growth of society. The demand for higher levels of comfort in buildings leads to intensive demand for new technologies, which has been reflected in energy consumption (Fernandes, 2017).

In a global perspective, buildings are responsible for 40% of total energy consumption and for about 40% of energy-related CO2 emissions and forecasts indicate an increase in energy consumption in this sector. Progress towards sustainable buildings and construction is advancing, but the improvements are not yet keeping pace with the growth of the housing sector and the increasing demand for energy services (UN Environment, 2017).

Even though energy-efficient solutions are already being incorporated into new constructions, existing buildings account for the majority of the building stock that will be in operation in the near future. Gordon Holness, a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), said that 75 to 80 percent of the buildings that will exist in 2030 already existed in 2010 (ASHRAE, 2010). The survey data suggests that there is an opportunity to reduce the construction sector's contribution to global energy consumption by reducing energy use in existing buildings.

The reduction of energy consumption in existing buildings consists of two synergetic approaches: (1) to reduce energy demand by implementing energy efficiency measures and (2) to use renewable energy systems to offset the remaining energy demand of buildings (Hayter et. al., 2011).

In summary, the rehabilitation of existing buildings, in addition to the efficient use of energy and the use of renewable energy sources in buildings, are key solutions to the problem. However, it is important to understand the characteristics of the existing constructions.

In a global context, which includes Europe, the USA and Latin American countries, there is a process of degradation of buildings and urban environments. This phenomenon is related to several factors that include the absence of public and private interventions and investments for long periods, the growing real estate speculation, the relocation of former residents to other regions far from the centre and the very functional obsolescence resulting from the lack of renewal of uses (Marinho, 2011).

In a specific context, such as the example of Portugal, at the end of the 20th century, the country witnessed a disproportionate growth in civil construction, which resulted in many buildings without the appropriate quality. Moreover, historical centres suffer more and more from the degradation of heritage, either by natural factors, by abandonment, or simply because they are not suitable for today (Paiva et. al., 2019).

In this scenario, the buildings do not meet the needs required at present, which makes the need for their rehabilitation increasingly common. Rehabilitation can be defined as an intervention in a building aimed at correcting the anomalies caused over the years that affect the quality, aesthetics, comfort and safety of a building. The result of this modernization process is the improvement of the construction performance, so that it meets the current levels of requirements while respecting the original architecture (Paiva et. al., 2019).

On this basis, it is relevant to consider intervening in the energy performance of buildings in order to make them energy efficient, taking into account the needs of the dwelling, in particular thermal comfort, well-being and health conditions for their users, through reduction of energy consumption (Machado, 2014).

1.2 Objectives

Over the years, the need for building rehabilitation is growing significantly, due to the fact that buildings no longer meet the comfort needs demanded by their users. Furthermore, the buildings have not evolved with the new technologies, making them obsolete in matters such as energy-efficient operational systems.

A rehabilitation project that proposes not only an aesthetic renovation but also an improvement in the energy performance of the building, needs to present solutions to make the building energy-efficient. The possible approaches are numerous, and can include solutions such as shading, insulation, heating, cooling and ventilation systems, among others, which in combination can result in buildings with optimal energy efficiency.

However, regardless of the approach adopted, the performance of the building needs to respect pre-established values in each country's legislation in order to obtain its energy certificate.

In this context, the aim of this work is to carry out a comparative analysis of energy legislation and certificates in Austria, Portugal and Brazil. It is also intended to determine rehabilitation solutions for existing buildings adapted to the climate where they are located.

In order to achieve this objective, the standards provided in each of the legislation and certificates will be applied to case studies in buildings to be rehabilitated in their respective countries. The result of this application will present results that will be relevant for the comparative analysis initially proposed.

1.3 Methodology

With the purpose of reaching the defined objectives, the following methodology was adopted:

Rehabilitation	• Research in the context of rehabilitation, with regard to its constitution and functioning;
Climate Data	• Overview of the climate zones of the places where de case studies will be built; • Study of Sun Position and Mollier Diagrams of the local climates.
Legislation and Energy Certification Sistems	• Analysis of the values imposed in each country's legislation; • Analysis of the NZEB concept in each country; • Presentation of the energy certification systems applied.
Case Studies	• Study of the building designs in Austria, Portugal and Brazil; • Calculation of current energy demand; • Comparison with reference values imposed and proposals for improvements and optimization.
Comparative Analysis	• Comparative analysis of energy certification systems implemented in Austria, Portugal and Brazil. • Proposal of improvements in the energy certification systems if necessary.
Conclusion and Future Work	• Conclusions; • Proposal for Future work

In order to achieve the objectives proposed in this work, three different case studies will be considered. The first one is located in Kitzbühel, Tyrol, Austria; the second case study is located in Vila Real, in the district of Vila Real, Portugal; finally, the third case study is located in the city of Goiânia, in the state of Goiás, Brazil.

1.4 Work Organization

In addition to the chapter 1, this work is organised into 6 more chapters.

In the second chapter, a review is made regarding the rehabilitation of buildings, starting with its definition, application, and historical framework. In addition, a review is carried out in the context of energy-efficiency in rehabilitation.

In the third chapter, an analysis of climate zones in an international context is made. This chapter gives more relevance to the zones where the case studies presented in this work are located.

In Chapter 4 the legislation of each country referred to in that study is presented. In addition, the reference values to obtain an energy certificate will be presented.

In Chapter 5, the buildings designs that will be studied in this work will be presented. Images, plans, and description of the building elements are some relevant topics of this chapter. In addition, the calculations of the actual energy demand of each building will be presented, together with the analysis of where the loads are coming from. Finally, it will be identified whether the buildings have values that respect the energy certification systems of their countries. Also, a proposed optimization will be highlighted.

In Chapter 6 a comparative analysis of the energy regulations and certification systems used in the case studies will be presented.

In Chapter 7, the main conclusions of this work are presented, as well as proposals for future work.

Chapter 2

Rehabilitation

2. REHABILITATION

2.1 Theoretical Framework

Rehabilitation can be defined as the set of operations aimed at ensuring the possibility of full re-use of an existing building, adapting it to contemporary requirements, and establishing a compromise between its original identity and that resulting from the rehabilitation itself.

This means that in order to talk about rehabilitation, one has to take into account the knowledge and respect for the pre-existing reality of the operation. However, improvements have to be introduced in the performance of the building in several areas, from safety to comfort and economy (Appleton, 2014).

Rehabilitation is necessary in constructions where, anomalies are observed, stability problems are encountered, if there is a need to change the type of use of the building or where for some reason the acting forces increase. This may contain all the circumstances mentioned above, or just one of them (Lopes, 2009).

According to the Lisbon Charter (1995), the integrated rehabilitation is an innovative contribution to the preservation and vivification of cities' heritage, both in terms of the built environment and the social fabric, which inhabits it and ensures its identity.

It also defines rehabilitation of a building as all the works that aim the recovery and improvement of a construction, solving the anomalies and safety accumulated over the years, by carrying out a series of modernization to improve its performance to close to current levels of demand (ANAIS, 1995).

Thus, rehabilitation can involve the repair of all building elements, from damage of roofs, exterior and interior walls, doors and windows or the solution of mechanical, electrical, plumbing and fire protection systems, to the replacement or strengthening of damaged structural components. In the end, it is intended that the building has more sophisticated and automated equipment, which complies with current building standards, but at the same time respects the initial design (Sena, 2019).

Building rehabilitation brings countless economic, social, environmental, and cultural advantages to a country. Although it imposes challenges on society as a whole, its practice is essential to the current reality in the construction sector, where new buildings are increasingly scarce and old ones need to be repaired (Sena, 2019).

2.2 Historical Framework

Man has always felt the need to make the objects he builds last with a certain utility and, depending on the changes he is facing with each passing season, he tries to adapt them (Sousa, 2016).

After the construction of a building, the human being tends to adapt it to the needs felt in order to improve his living conditions. From that moment on, when it no longer has the function for which it was conceived, it is submitted to changes in relation to the initial project, in order to continue to give usefulness to it, and to meet the standards and requirements that are required by the present way of life (Sousa, 2016).

The main concern that made the human being proceed with the construction of buildings was to be protected from the agents of nature in order to feel safe. The development of buildings over time are portraits that reveal this same commitment. However, for a long time, the only concerns were the safety and comfort of those who enjoyed the building, without any historical, socio-economic or environmental conscience (Sousa, 2016).

It was only in the 20th century that the first questions about heritage and the need for rehabilitation arose, resulting in the creation of charts and recommendations that started a new era in construction (Silva, 2017).

These charts act at the international level as a reference on how to interfere in the architectural heritage, which must be adapted to the specific needs of each country and current technological uses. These charts, in recent years, due to the scarcity of resources and the pollution caused by the construction sector, have also begun to highlight environmental and ecological concerns (Sousa, 2016).

2.3 Energy Efficiency in Rehabilitation

Due to the depletion of fossil fuels and due to the remarkable global effects of greenhouse gas emissions, energy-efficient measures are being implemented in almost every sector that has a relation to energy and energy use. Buildings sector is one of these sectors, and a broad range of research activities are being carried out to find ways to decrease the energy demand and consumption of buildings (Kazanci et. al, 2014).

As already mentioned, buildings are responsible for 36% of total energy consumption and about 40% of energy-related CO_2 emissions from a global perspective. Also, 80% of the buildings that will exist in 1 decade already existed 10 years ago. The rehabilitation of the existing building stock is, therefore, the key to meeting to a long-term climate and energy goals.

The EU is taking up this rehabilitation challenge through policies such as the Energy Performance of Buildings (EPBD) and Energy Efficiency (EED) directives.

The first one specifies that Member States shall take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements (EPBD, 2010).

The second one highlights that Member States shall establish a long-term strategy to mobilise investment in the renovation of the national stock of residential and commercial buildings. One strategy includes an identification of cost-effective approaches to renovations relevant to the building type and climate zone (EED, 2012).

Furthermore, a wide range of policies and support measures are covered by the EPBD, with the intention of helping EU national governments to increase the energy performance of buildings and improve the existing stock of buildings. From the policies that the directive covers, the following can be highlighted:

- EU countries should set minimum energy performance requirements for existing buildings undergoing major renovation and for the replacement or retrofitting of building elements such as heating and cooling systems, roofs and walls;
- Energy performance certificates should be issued when a building is sold or rented out and inspection programmes for heating and air conditioning systems should be introduced;
- Health and well-being of building users, for example by taking into account air quality and ventilation (EPBD, 2010).

In 2018, EPBD underwent a revision that implies that existing buildings must also become energy efficient, which is supposed to be adapted to the laws of the member countries of the European union.

2.3.1 Energy Performance of Buildings

A rehabilitation project that seeks to improve the energy performance of existing buildings must pursue the best solutions adapted to the structure of the building. The building's physical features have a great impact on its energy performance, as well as having a direct influence on the well-being and comfort of the users.

Thus, the building physics deals mainly with the flows of energy, both natural and artificial, within and through buildings. The understanding and application of building engineering physics allows the design and construction of high-performance buildings; these are buildings which are comfortable and functional yet using natural resources efficiently and minimising the environmental impacts of their construction and operation (King, 2010).

Several aspects of building physics can have a positive impact on their performance, in particular thermal insulation, air tightness, surround shading and efficient windows.

Thermal insulation is the process of reducing heat transfer between objects in thermal contact or in the range of radiative influence. It consists of materials of low thermal conductivity combined to obtain an even lower thermal conductivity of the system. The reduced thermal conductivity provides a better thermal insulation system that consumes less energy for cooling and heating in the use phase. Thus, thermal insulation can be achieved with specially designed methods or processes as well as suitable object shapes and materials (Connor, 2019).

The benefits of increasing insulation are evident in a typical winter situation, because the lower the thermal transmission coefficient, the lower the losses through the envelope, and consequently, the lower the heating expenditure. In countries with long heating seasons and mild and short summers, energy consumption can be considerably reduced by adopting highly insulated envelopes (Chvatal, 2007).

On the other hand, the thermal insulation also provides benefits in typical summer situations. The so-called summer thermal insulation reduces undesired heat input and thus the overheating of rooms during the height of summer (Kienzlen et. al., 2014). In Figure 1 a scheme of thermal insulation in winter and summer situations is presented.

Figure 1- Thermal Insulation Scheme (Isowall Group, 2020).

Thermal insulation, if applied to existing buildings, can therefore have a major influence on their energy performance, regardless of the climate zone in which the building is located.

Air tightness, on the contrary, is the fundamental building property that impacts infiltration. Infiltration is the movement of air through leaks, cracks, or other adventitious openings in the building envelope (Sherman et. al., 2004).

It is relevant because it impacts building energy use, once the infiltration transports contaminants between indoor air and outdoor air. From the energy point of view, it is almost always desirable to increase air tightness (Sherman et. al., 2004). Thus, the basic demand is that air barrier should remain continuous in structural joints, for example, the junction between the external wall and roof structure (Aho et. al., 2008).

It is common knowledge that buildings under rehabilitation can suffer from problems related to air tightness, as buildings generally endure degradation of the joints in the structure.

However, buildings can't be hermetic. Studies prove that the temperature and humidity control process was the first example of air conditioning by a mechanical process, being the pionner of the whole industry of HVAC (heating, ventilation and air conditioning) and environmental comfort control. This happened since completely airtight buildings can result in problems of poor air quality and condensation (Ribeiro et. al., 2004).

Concerning surround shading, however, the effects can be either positive or negative depending upon the site-specific circumstances of the properties involved. A potential benefit of shading for adjacent buildings may be a cooling effect during warm weather. Negative consequences of shading include the loss of natural light for passive or active solar energy applications or the loss of warming influences during cool weather (Los Angeles Department of City Planning, 2002).

Finally, energy efficient windows are essential for both new and existing buildings. Heat loss and heat gain through windows are responsible for 25%–30% of residential buildings cooling and heating energy use.

Many features and technologies make windows more energy efficient and improve the durability, aesthetics, and functionality. When selecting windows, it is important to consider the frame materials, the glazing or glass features, gas fills and spacers, and the type of operation. Improving the thermal resistance of the frame and glazing can contribute to a window's overall energy efficiency, particularly its U-factor (Office of Energy Efficiency & Renewable Energy of U.S. Department of Energy, 2020).

2.4 Summary

All in all, it is clear that in recent decades the idea of rehabilitating old buildings has gained strength. One of the main reasons for this has been the growing concern with sustainability topics and the preservation of the historic city centers.

The energy efficiency of buildings is a major focus for contributing to the improvement of the energy sector worldwide. Therefore, the analysis of the energy performance of buildings, the heat transmission through the envelope are very relevant, which gives great importance to the building envelope in order to improve its energy efficiency.

Whether using passive or renewable energy techniques, the construction or rehabilitation of buildings with nearly zero energy needs is the next step in the construction industry all over the world, to increase their energy efficiency.

Chapter 3

Climate Zones

3. CLIMATE ZONES

3.1 Theoretical review

The design of a building must meet both energy-efficiency and user comfort conditions. Knowing the climate data of a site allows the professional responsible for the project of a building to identify the periods of greatest probability of discomfort and, consequently, to define the strategies that should be included in the project to overcome these conditions.

To make a clear and organized analysis of the climate, it is important to understand the general climate characteristics of a region in terms of sun, clouds, temperature, winds, humidity and precipitation. Besides, local climate conditions can also influence the building's performance, such as vegetation, topography, soil type and the presence of natural or artificial obstacles (Lamberts, 2020).

The climatic particularities of the site may represent additional benefits or difficulties in the elaboration of a project of rehabilitation of a building. Thus, it is important to determine building practices based on climate zones to achieve the most energy savings.

For this reason, this chapter provides some general guidance on the definition of various climate regions in an international context, based on the Köppen-Geiger climate classification and also on data provided by specialised meteorological institutions.

3.2 Worldwide Framework

The first quantitative classification of world climates was presented by the German scientist Wladimir Köppen in 1900 and it has been available as world map updated by Rudolf Geiger in 1954 and 1961. Their effective classification was constructed on the basis of five vegetation groups distinguishing between plants of the tropical or equatorial zone (A), the arid zone (B), the temperate zone (C), the continental or cold zone (D) and the polar zone (E). A second letter in the classification considers the precipitation (e.g. Df for snow and fully humid), a third letter the air temperature (e.g. Dfc for snow, fully humid with cool summer) (Kottek et. al., 2006).

In Table 1 the classifications developed by Köppen-Geiger, showing the climate classification scheme symbols description and its criteria are presented.

Table 1- Köppen-Geiger climate classification (Peel et. al., 2007).

First	*Second*	*Third*	*Description*	*Criteria*
A			**Tropical**	**Tcold≥18**
	f		- Rainforest	Pdry≥60
	m		- Monsoon	Not (Af) & Pdry≥100–MAP/25
	w		- Savannah	Not (Af) & Pdry<100–MAP/25
B			**Arid**	**MAP<10×Pthreshold**
	w		- Desert	MAP<5×Pthreshold
	s		- Steppe	MAP≥5×Pthreshold
		h	- Hot	MAT≥18
		k	- Cold	MAT<18
C			**Temperate**	**Thot>10 & 0<Tcold<18**
	s		- Dry Summer	Psdry<40 & Psdry< Pwwet/3
	w		- Dry Winter	Pwdry<Pswet/10
	f		- No Dry Season	Not (Cs) or (Cw)
		a	- Hot Summer	Thot≥22
		b	- Warm Summer	Not (a) & Tmon10≥4
		c	- Cold Summer	Not (a or b) & 1≤Tmon10<4
D			**Continental (Cold)**	**Thot>10 & Tcold≤0**
	s		- Dry Summer	Psdry<40 & Psdry<Pwwet/3
	w		- Dry Winter	Pwdry<Pswet/10
	f		- No Dry Season	Not (Ds) or (Dw)
		a	- Hot Summer	Thot≥22
		b	- Warm Summer	Not (a) & Tmon10≥4
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & Tcold<–38
E			**Polar**	**Thot<10**
	T		- Tundra	Thot> 0
	F		- Frost (Ice Cap)	Thot≤0

According to the criteria notation presented: MAP = average annual precipitation; MAT = average annual temperature; Thot = temperature of the hottest month; Tcold = temperature of the coldest month; Tmon10 = number of months where the temperature is above 10°; Pdry = precipitation of the driest month; Psdry = precipitation of the driest month in summer; Pwdry = precipitation of the driest month in winter; Pswet = precipitation of the wettest month in summer; Pwwet = precipitation of the wettest month in winter; Pthreshold = varies according to the following rules (if 70% of MAP occurs in winter then Pthreshold = 2*MAT, if 70% of MAP occurs in summer then Pthreshold = 2*MAT + 28, otherwise Pthreshold = 2*MAT + 14). Summer (winter) is defined as the warmer (cooler) six-month period of Apr/May/Jun/Jul/Aug/Sep and Oct/Nov/Dec/Jan/Feb/Mar (Peel et. al., 2007).

Figure 2 represents the world Köppen-Geiger climate type map.

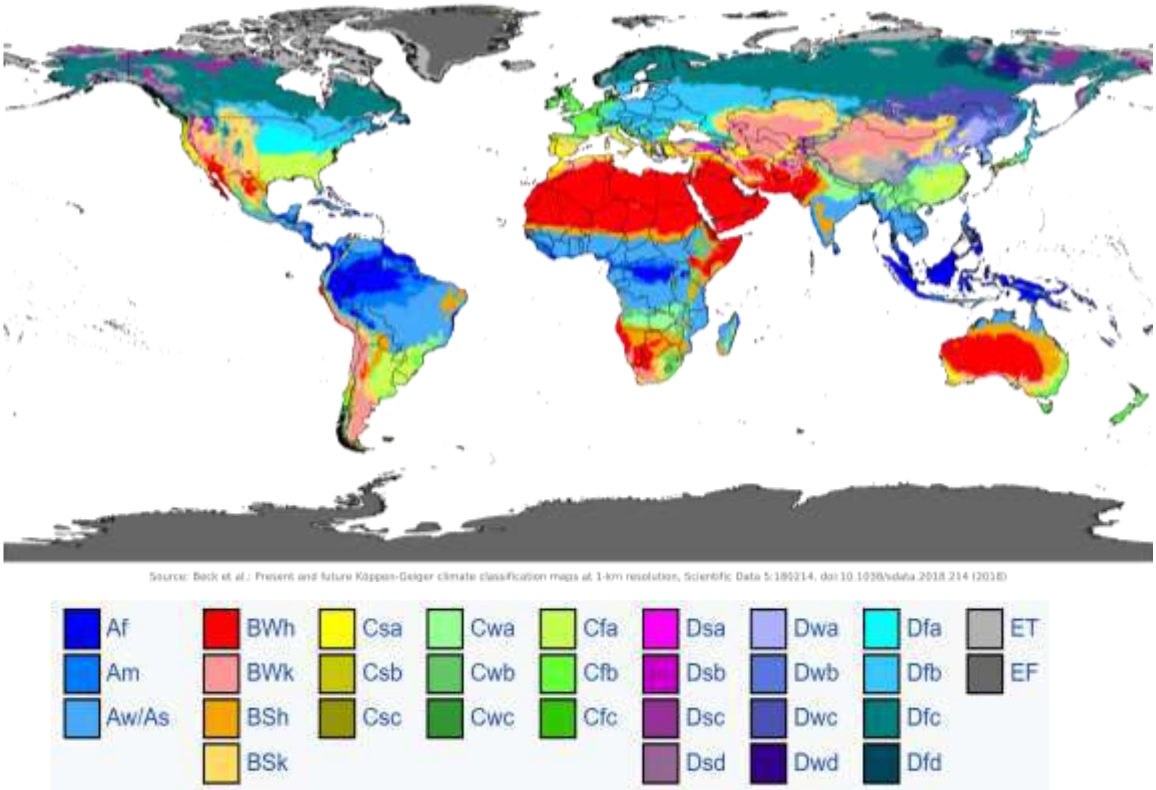


Figure 2- Köppen-Geiger Climate Classification Map (Peel, et. al., 2007).

3.3 Climate in Austria, Portugal and Brazil.

Austria, located in the European heartland, lies within a temperate climatic zone. Austria’s landscapes include major and minor mountain ranges, hills and plains. Weather conditions vary only slightly across the country, the lowland regions in the north and east have more continental influenced conditions with colder winters and hotter summers with moderate precipitation throughout the year. The south-eastern areas of Austria have longer and warmer summers, almost Mediterranean-like summers.

According to the Köppen-Geiger classification (Figure 3), the climate of Austria can be classified mostly as Cfb Climate; a warm temperate humid climate. The climate of the Mountainous Regions of Austria can be classified as Dfb Climate, a humid snow climate. Still in the Alps region, it is possible to identify polar and continental zones, represented in the EF, ET and Dfc climate types (Austrian Embassy, 2020).

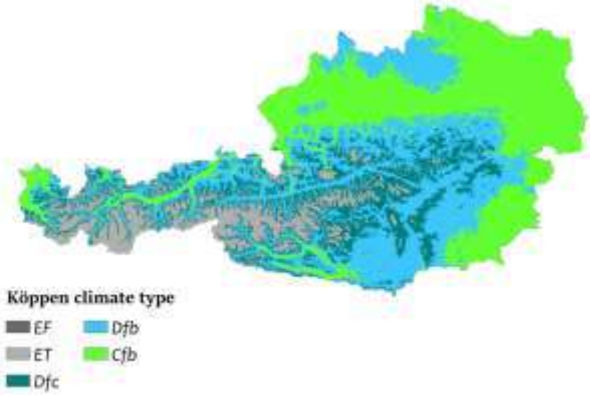


Figure 3- Climate classification for Austria, according to the Köppen criteria (Peterson, 2016).

On the other hand, Portugal is almost completely classified in the C zone. The results obtained by the classification map for climate (Figure 4), serve to confirm that for most of the mainland territory the climate is temperate continental, checking the subtype Cs (a temperate climate with dry summer) and the following varieties:

Csa, temperate climate with warm summer and dry in the interior regions of the Douro Valley (part of the districts of Vila Real and Bragança), as well as in regions south of the mountain system Montejunto-Estrela (except on the west coast of Alentejo and Algarve).

Csb, temperate climate with dry and mild summer, in almost all regions of the northern mountain system Montejunto-Estrela and the regions of the west coast of Alentejo and Algarve.

In a small region of Alentejo, in the district of Beja, is Arid Climate (B zone) and subtype BS (steppe climate), BSK variety (cold steppe climate of mid-latitude) (IMPA, 2020).

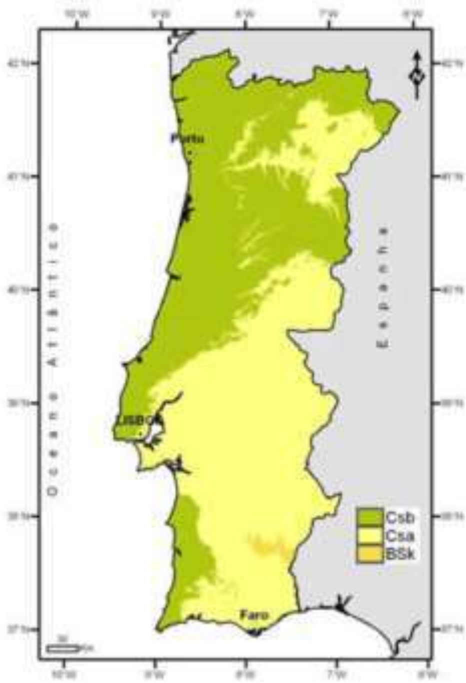


Figure 4- Climate classification for Portugal, according to the Köppen criteria (IMPA, 2020).

Finally, Brazil is a country whose extension is of continental dimensions. The spatial distribution of its territory is almost completely within the intertropical range of the planet, the area with the most intense solar radiation on the globe. For this reason, the Brazilian climatic configuration is expressed mainly in the considerable brightness (sunshine) and in the high temperatures allied to the rainfall (hot and humid climate).

However, considering the Köppen-Geiger classification, the climate in Brazil is much more complex. Three zones and 12 types of climates were classified throughout Brazil (Figure 5). Divided in 26 states, tropical climate, A zone, was the one with the largest area, representing more than 80% of the Brazilian territory, occurring in all regions of the country, except in the states of Rio Grande do Sul and Santa Catarina and great part of Paraná in the Southern region.

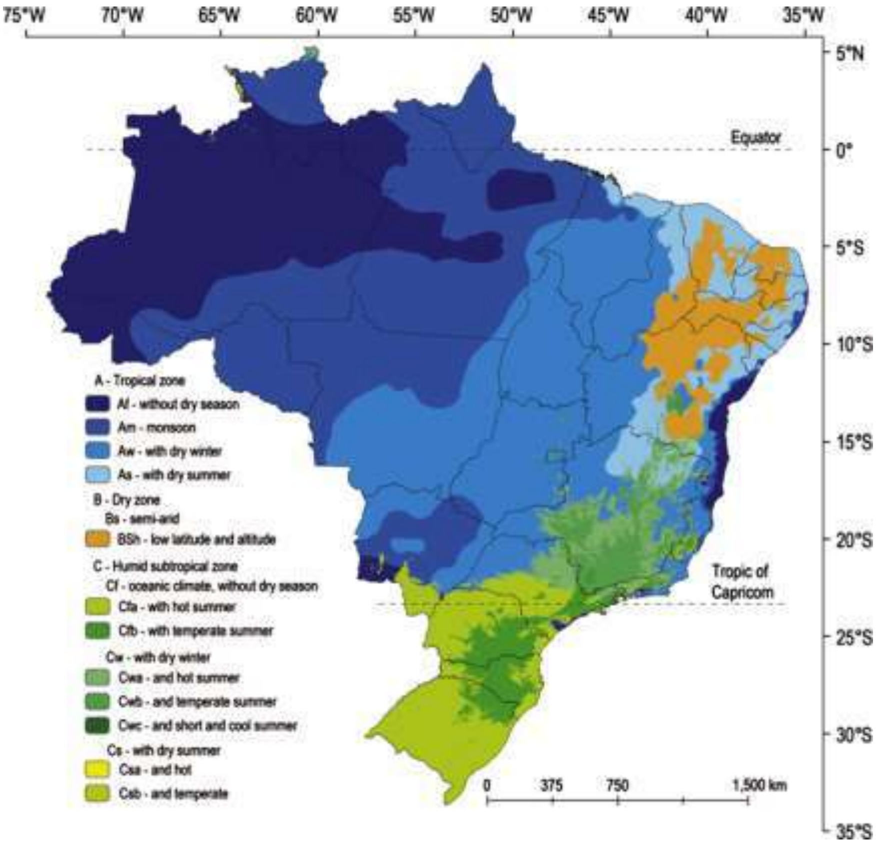


Figure 5- Climate classification for Brazil, according to the Köppen criteria (Mendonça et. al., 2011).

Semi-arid climate, classified in the B zone, is notably the typical climate of north-eastern Brazil, occurring basically in landscapes where annual rainfall drops significantly. It is about an enclave of scarce rainfall in the Brazilian tropical region.

Subtropical or temperate climate (C zone) covers around 13% of the Brazilian territory, which is mainly in the southern region, in their plateaus and mountains. The Köppen's key criteria worked well for Brazil since was noted that below and above the Tropic of Capricorn there is a dominance of subtropical and tropical climates, respectively (Mendonça et. al., 2011).

3.4 Local Climates

After considering the global and regional scale climates, it is necessary to analyse the local climates of the places where the three buildings, studied in this work, are located

One of the buildings is located in Kitzbühel, Tyrol, Austria, the second one in Vila Real, Portugal, and the third one in Goiânia, Goiás, Brazil.

For this reason, the local climates of these cities will be analysed by reviewing the Mollier-diagrams. These diagrams show a correlation between temperature and humidity. Each point on the graphic represents the value of these variables identified at each hour of the year. Thus, it is possible to prove the levels of humidity and the variation of temperature throughout the year.

The graph of the sun position will also be analysed. The study of the insolation of a building is very relevant to analyse its thermal comfort. A building located in the northern hemisphere does not receive the same light impact as a building located in the southern hemisphere, however, the closer to the equator, the similarities among the climates tend to increase. In addition, for the same reason, a building that is further from the equator cannot be compared to one that is closer.

In practice, this study can influence choice of the protection of facades and their coatings. As well as that, it can influence the design of the roof and the location of the windows, in order to promote shading and to optimize the light penetration into the building.

The values used for the construction of the Mollier-diagrams and for the graphics of the sun position were obtained through data provided by the local meteorological institutes.

3.4.1 Kitzbühel, Austria

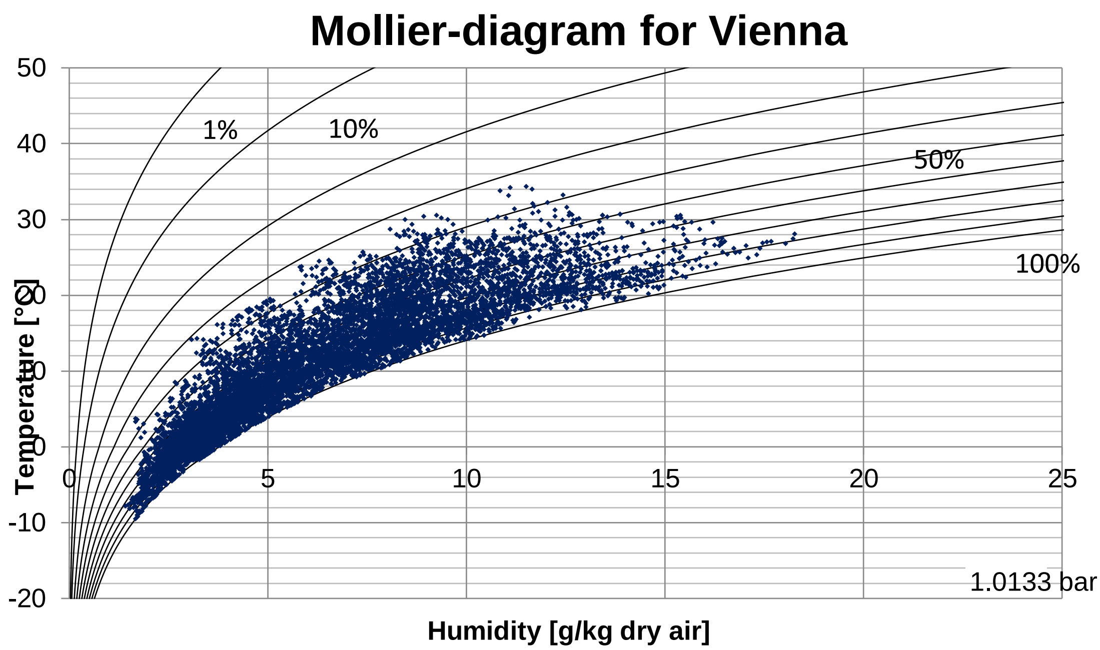
Kitzbühel is a medieval town in Tyrol, Austria, near the river Kitzbühler Ache (Figure 6). It is the administrative centre of the Kitzbühel district. The region is framed by the grassy mountains of the south, which have become particularly popular due to their untouched nature and easy scenic walks (Kitzbuehel City Hall, 2020).

Furthermore, the geographical coordinates of Kitzbühel are 47.446 deg. latitude, 12.392 deg. longitude, and 1,027 m altitude. Its topography within 3 kilometres contains large variations in altitude, with a maximum altitude variation of 956 meters and an average altitude 986 meters.

Figure 6- Kitzbühel's location in comparison to the rest of Austria (Google Maps, 2020).

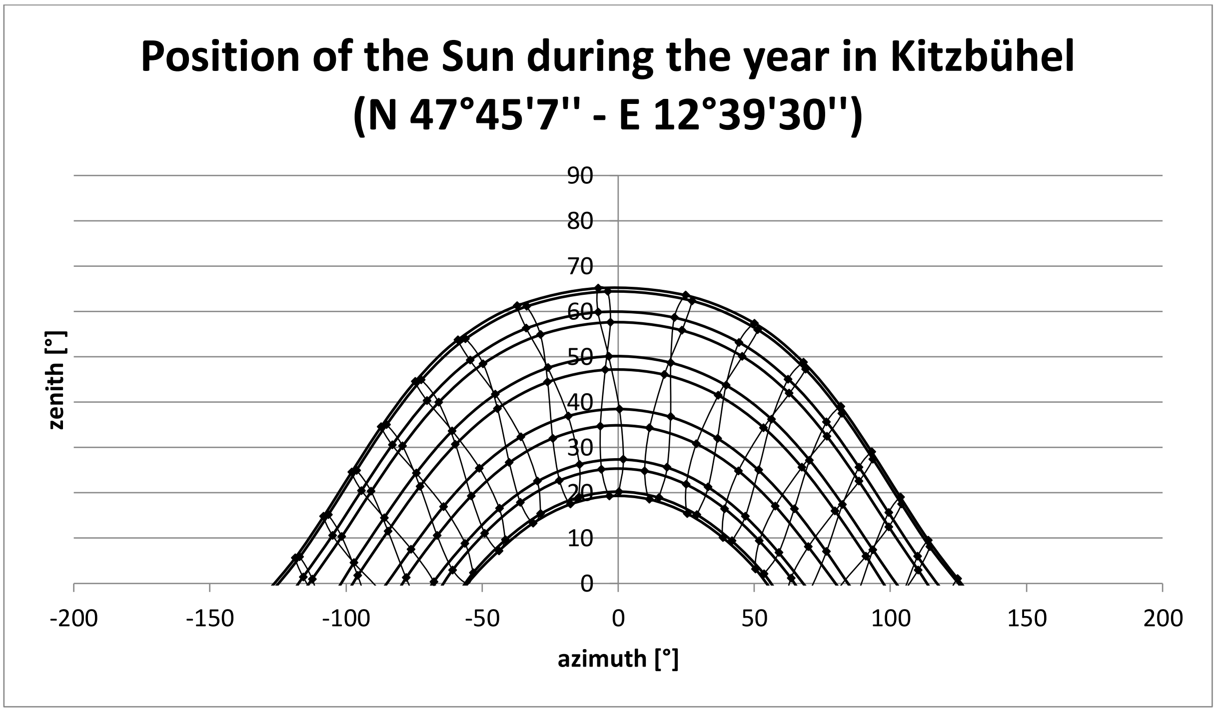
For this study, the Mollier-Diagram (Graphic 1) presents the temperature and humidity data of Vienna, the Austrian capital. Although relatively distant, both cities have temperate climates with cold winters and moderate summers, which validates the use of such data.

It is noticeable that the temperature is around 0°C (+/- 10°) throughout most of the year, with the exception of summer days, which remain around 20°C. The city does not have high levels of humidity compared to tropical climates, for example.



Graphic 1- Mollier-Diagram for Vienna.

Graphic 2 represents the position of the sun during the year in Kitzbühel. By identifying the position of the sun, one can see that the city of Kitzbühel is located in the northern hemisphere, and that the sun never has a 90º angle to the ground. In practice, this represents longer days in summer, with higher solar incidence, while in winter the days are shorter and with lower solar incidence.



Graphic 2- Position of the Sun in Kitzbühel.

3.4.2 Vila Real, Portugal

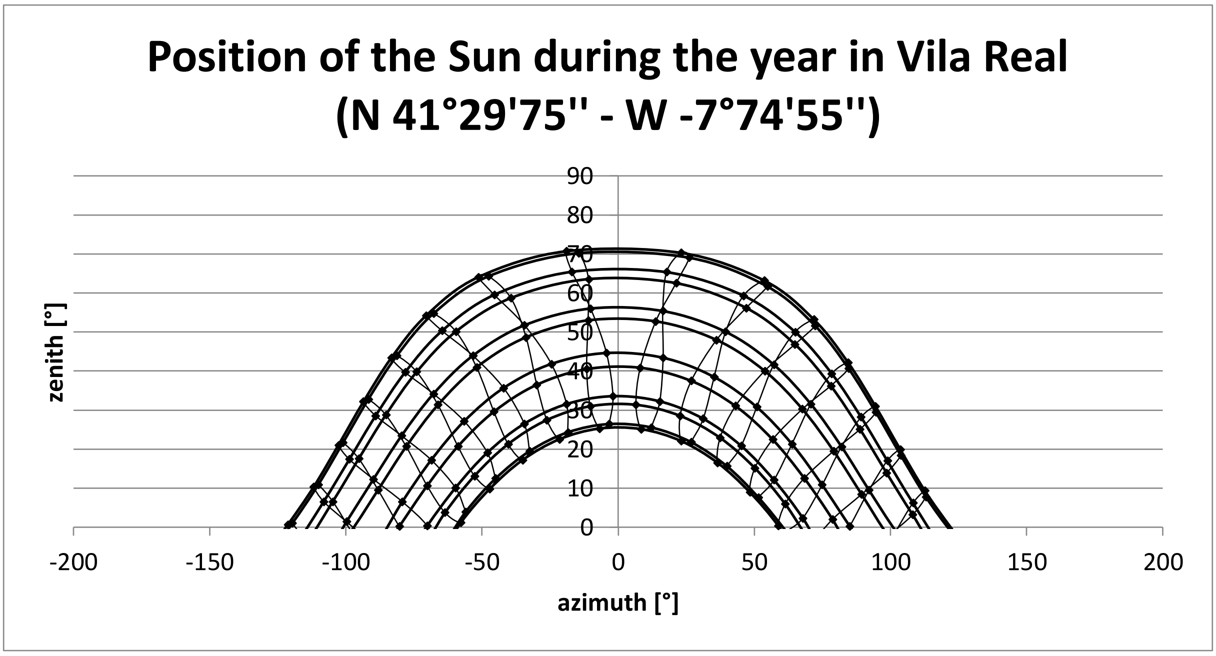
The city of Vila Real is located at about 450 meters of altitude, on the right bank of the river Corgo, one of the Douro's tributaries. It is located in a plateau surrounded by high mountains, in which the Marão (1416 m) and Alvão (1330 m) mountains ranges abound (Figure 7).

It lies approximately 85 kilometres, in a straight line, from the Atlantic Ocean, which lies to the west. To the south, in 15 kilometres there is River Douro, while to the north, it is about 65 kilometres from the border with Galicia, Spain. Vila Real is the county seat and district capital (Vila Real City Hall, 2020).

Vila Real has well-defined seasons, such as rainy and foggy autumns, very hot summers, mild springs and relatively cold winters, with occasional and not very frequent snow.

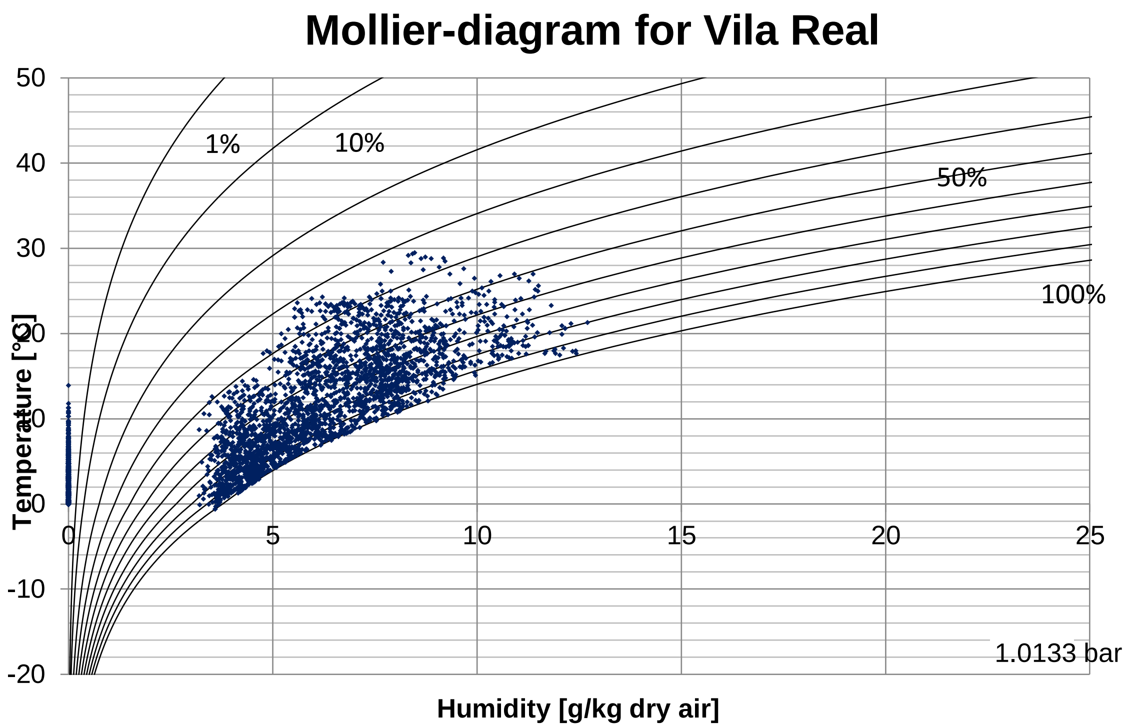
Figure 7- Vila Real's location in comparison to Portugal and Spain (Google Maps, 2020).

Graphic 3 represents the position of the sun during the year in Vila Real. This graphic has similarities to Kitzbühel's graphic. Located in the northern hemisphere, it also has longer days in summer and shorter days in winter, but not as discrepant as in the Austrian town.



Graphic 3- Position of the Sun in Vila Real.

Analysing the Mollier-diagram (Graphic 4) it is possible to see that Vila Real does not present high levels of humidity and most of the year the temperature varies from 0 to 20°C. Meanwhile, in the summer, the city has high temperatures at around 30ºC. In practice, this shows that there is no great need to worry about complex cooling systems, however, it is necessary to create measures that can be adopted in the summer so that comfort is maintained for users at this time of year. Finally, the graphic highlights as there is no need to think about air dehumidification procedures.



Graphic 4- Mollier-diagram for Vila Real.

3.4.3 Goiânia, Brazil

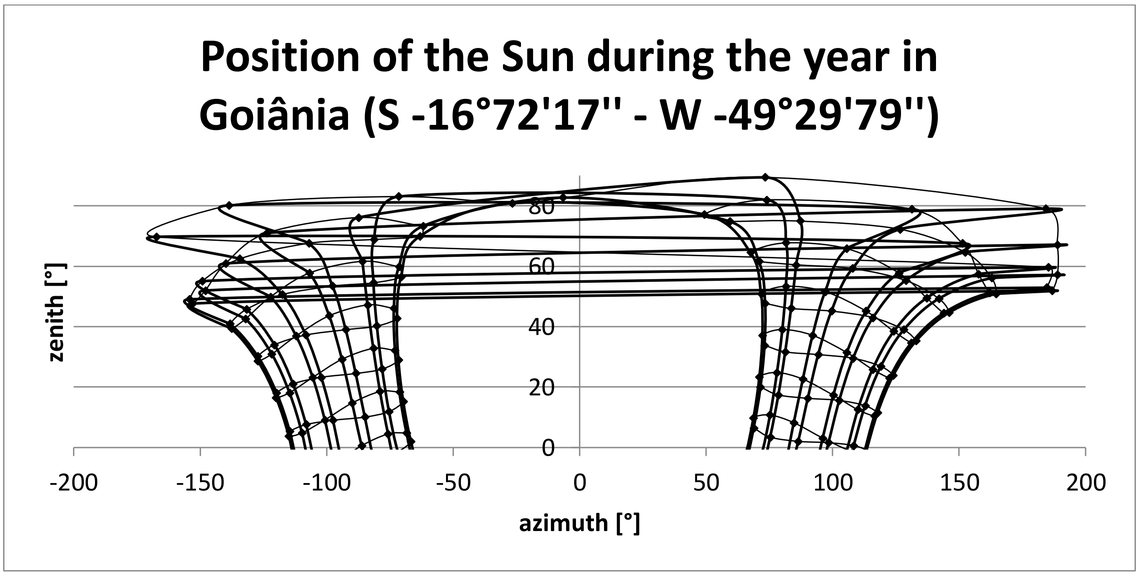
Capital of the State of Goiás, Goiânia is among the cities with the best quality of life in the country. Brazilian city with the largest green area per inhabitant (94 m²), the city stands out for implementing a model of urban development coupled with a consistent policy of environmental responsibility (Goiânia City Hall, 2020).

Considering the purposes of this work, it is relevant to analyse some topographic data. Thus, the geographical coordinates of Goiânia are -16.679 deg. latitude, -49.254 deg. longitude, and 753 m altitude. Also, the topography within 3 kilometres of Goiânia contains only modest variations in elevation, with a maximum elevation change of 139 meters and an average elevation above sea level of 768 meters.

Figure 8 shows the position of Goiânia in relation to Brazil. It is possible to notice that the city is located right in the center of the country, in the Midwest region, far from the coast and the Amazon rainforest, which influences on issues such as humidity and rainfall.

Figure 8- Goiânia's location in comparison to the rest of Brazil (Google Maps, 2020).

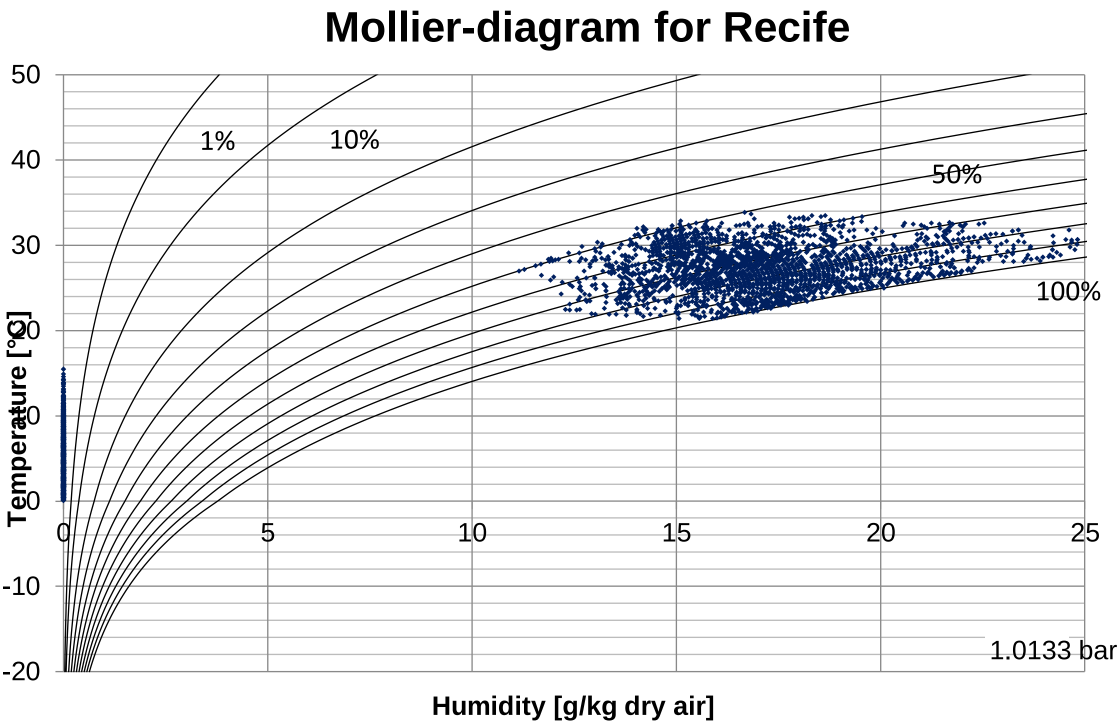
Graphic 5 represents the position of the sun during the year in Goiânia. The Brazilian city is located in the southern hemisphere, very close to the equator. This implies that usually the sun presents an angle of about 90º with the ground, besides that the hours of solar incidence are almost constant throughout the year.



Graphic 5- Position of the sun in Goiânia.

The Mollier-diagram (Graphic 6) illustrates the values found for the city of Recife, Brazil. Despite being relatively distant, Goiânia and Recife have similar climates in relation to temperature and humidity, therefore, the data presented in the graph can be considered for the city in focus of the present work. It is noted that the city has a high humidity index, in addition to high temperature levels, always being around 30°C.

With the data presented in the graph, it is possible to come to the conclusion that it is not necessary to think about heating systems for the buildings. However, one problem that these buildings may present is related to the high humidity.



Graphic 6- Mollier-diagram for Recife.

3.5 Summary

In summary, it is clear that the climate zone has a great influence on the environmental comfort of buildings. In countries in temperate zones, there is great concern about the heating of buildings, especially in the winter months, while countries in tropical zones have particular concerns about the cooling of environments.

In the case studies that will be presented in this study, three buildings in different climatic zones are presented. In Austria, a building with exclusively heating concerns will be studied, while in Brazil, these concerns are exclusively related to cooling and in Portugal, a country with cold winters and hot summers, both situations need to be considered.

Finally, the importance of the study of solar radiation and humidity in the design of buildings located in different climate zones, is highlighted.

Chapter 4

Legislation and Energy Certification Systems

4. LEGISLATION AND ENERGY CERTIFICATION SYSTEMS ANALYSIS

4.1 Framework

As already mentioned before, buildings are responsible for about 40% of total energy consumption and energy-related CO2 emissions. For this reason, in recent years, sustainability and energy efficiency have been increasingly discussed and implemented, not only in Europe but also globally.

Thus, as a result of an economic crisis, the need to reduce costs and increase the energy autonomy of buildings arises. In addition, the growing awareness of climate change has created incentives to optimise energy efficiency, making the concept of nearly zero energy buildings stronger.

In fact, the concept of NZEB (Nearly Zero Energy Buildings) buildings that generate the energy they consume, has become a reality. This concept is increasingly present in the market, both because of the economic benefits associated with it, and because it is a measure that will help the planet (Azevedo, 2020). Figure 9 shows a sketch representing the NZEB buildings.

Figure 9- Example of a NZEB building (REHVA, 2020)

Over a four-year period, from 2012 to 2016, more than 1 million new or renovated buildings across Europe have met the requirements of a building with nearly zero energy needs).

This is a consequence of the European Commission's report published following the State of the Energy Union, which requires all new buildings from 2021 onwards to be NZEB. The document established by the Commission also states that all 23 Member States should have completed and brought into force national definitions of NZEB, considering the 2010 revision of the Energy Performance of Buildings Directive (EPBD) (Cardoso, 2020).

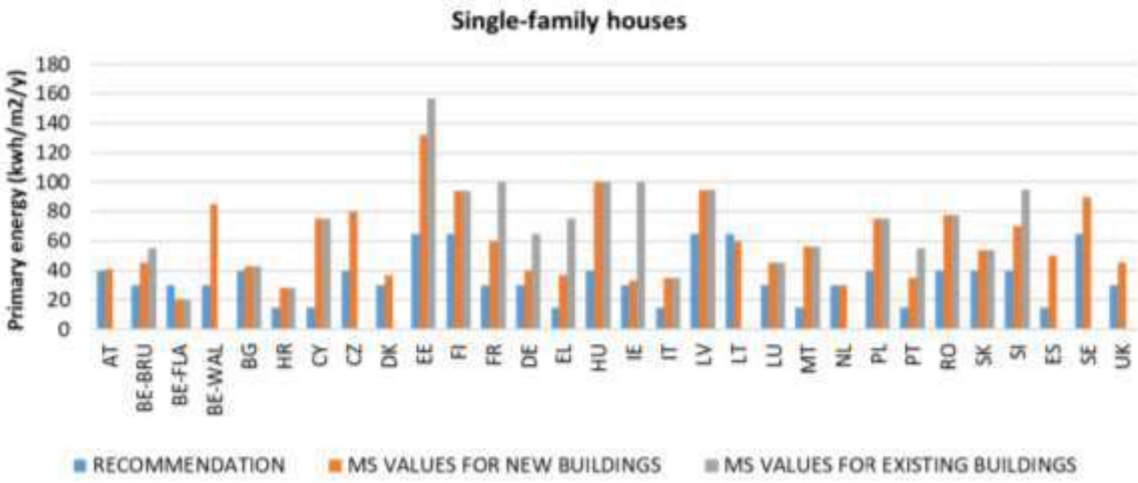
Not only the definitions of NZEB, but most Member States have also adopted financial, regulatory and information measures for the implementation of NZEB buildings (Cardoso, 2020).

According to the report from the Commission to the European Parliament and the Council (2020), the latest information reveals that not only do 23 Member States already have a complete national NZEB definitions, but they are also already in force. For the other Member States, the definition of what constitutes a NZEB is still being developed or revised.

The majority of the definitions already provided contain an energy indicator of primary energy use, and twelve of the definitions include the mandatory requirement to cover a minimum part of the demand for energy from renewable sources.

Approximately half of the Member States have developed an energy class or equivalent energy label for NZEB requirements. Half of the Member States have also provided the u-values required for walls, roofs, floors, windows, and doors. Moreover, at the level of ambition for the establishment of NZEB, the primary energy values of NZEB for most Member States have less stringent requirements than the reference values recommended by the Commission, both in residential and non-residential buildings (European Commission, 2020).

Graphic 7 provides an indicative comparison of NZEB primary energy consumption for new and existing single-family houses with the benchmarks recommended by the Commission.



Graphic 7- Comparison of NZEB single-family houses (European Commission, 2020).

Where MS stands for the Member-States of the European Union.

In South American countries, for instance, programmes already exist to certify the energy efficiency of buildings. In Brazil, for example, in 1984, the country experienced a critical moment in the supply of electrical energy, which led the federal government to create the Brazilian Labelling Program, with the objective of informing consumers about the efficiency of equipment. As of 2009, the label was applied to buildings, and the National Program for Electrical Energy Conservation (Procel) was created (MME, 2019).

In the following topics, the energy efficiency legislation in Austria, Portugal and Brazil will be discussed, as well as their reference values and energy certificates systems for buildings.

4.2 Austria

A document published by the Austrian Institute for Building Law in partnership with the Austrian Institute of Construction Engineering (OIB), in 2014, defines the "lowest energy building", named in German for NZEB buildings, and establishes goals in a national plan in accordance to Article 9 of the European Parliament's Directive 2010/31/EU on the energy performance of buildings. The document sets out the minimum energy performance requirements that must be implemented in buildings by 2020.

This document gives a detailed presentation of the practical implementation of Austria's definition of a lower energy consumption building. This is based on the Austrian heating demand (in kWh/m²a) including numerical indicators for primary energy demand (in kWh/m²a) and carbon dioxide emissions (in kg/m²a) (OIB, 2014).

The primary energy value is mandatory to be included by that European law. However, most of the counties, the nine Austrian states, agreed that not only the primary energy value, but also the CO2 emissions should be included into their standards (OIB, 2014).

The document also brings four indicators that define all the thermal insulation and energy saving requirements:

- Heating demand;
- Energy performance factor;
- Primary energy demand;
- Carbon dioxide emissions.

It is important to note that electricity demand for residential buildings is also taken into account. This is added to the amount of energy required for heating, cooling, ventilation and hot water during normal building use (OIB, 2014).

The minimum requirements refer to a reference climate. But the counties are free to decide to upper their requirements to their local climates.

The minimum energy performance requirements demanded by OIB for major rehabilitations of residential buildings until 2020 are shown in Table 2.

Table 2- OIB energy performance requirements (OIB, 2014).

	HWB_{max} [kWh/m²a]	**EEB_{max} [kWh/m²a]**	**$f_{GEE,max}$**	**PEB_{max} [kWh/m²a]**	**$CO2_{max}$ [kg/m²a]**
2014	23 x (1+2,5/ℓ_C)	means $HTEB_{Ref}$		230	38
	Or				
	25 x (1+2,5/ℓ_C)		1,10		
2016	21 x (1+2,5/ℓ_C)	means $HTEB_{Ref}$		220	36
	Or				
	25 x (1+2,5/ℓ_C)		1,05		
2018	19 x (1+2,5/ℓ_C)	means $HTEB_{Ref}$		210	34
	Or				
	25 x (1+2,5/ℓ_C)		1,00		
2020	17 x (1+2,5/ℓ_C)	means $HTEB_{Ref}$		200	32
	Or				
	25 x (1+2,5/ℓ_C)		0,95		

The table above shows the reference values in the national plan for maximum heat demand (HWB_{max}), maximum final energy demand (EEB_{max}), total energy efficiency factor ($f_{GEE,max}$), maximum primary energy demand (PEB_{max}), and finally carbon dioxide emissions ($CO2_{max}$). The heating demand is a function of the building shape factor (ℓ_C), while the final energy demand is related to the average heating technology energy demand climate reference ($HTEB_{Ref}$) (OIB, 2014).

Deviations from these minimum requirements are permitted if the necessary measures cannot be implemented for reasons of construction engineering or construction law.

The rehabilitation of individual components of the building or the replacement or installation of individual components of the technical system of the building must be carried out in such a way that take into account these individual measures, the above target value requirements can be achieved with additional measures - but not simultaneously implemented (OIB, 2014), as schematized in Figure 10.

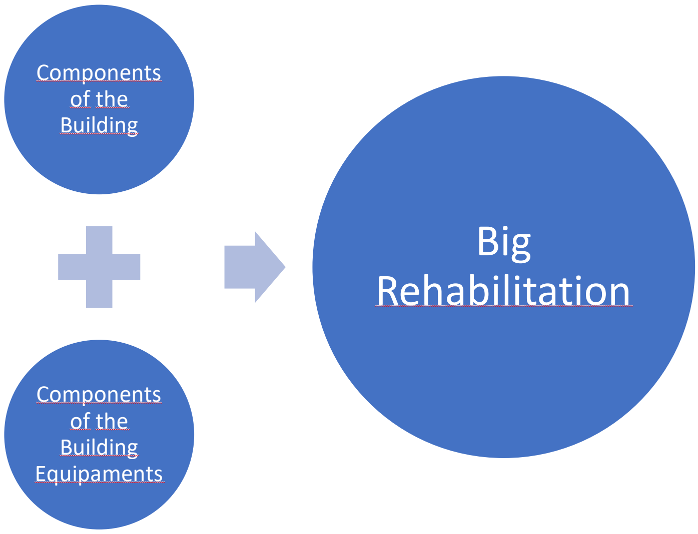


Figure 10- Rehabilitation of building's components.

The thermal transmittance values of the different construction elements of new or existing buildings in the event of rehabilitation (large or small renovations) are also defined in the OIB Guidelines. The latest revisions of the Directive have tightened the maximum U-Values (Table 3).

Table 3- Minimum requirements for U-Values (OIB, 2014).

Buillding Elements	U-value [W/m².K]
Exterior Wall	0,35
Roof	0,2
Window	1,4
Floor	0,4

Austrian standards such as ÖNORM H 5056, H 5057, H 5058, H 5059 and ÖNORM EN 13829 lay down the minimum requirements for heating, cooling and ventilation systems defined in the OIB guidelines. It is therefore established that the use of alternative energy systems with high efficiency is necessary both for new constructions and for rehabilitations. Among the specifications of the OIB Directive are the requirements for parts of the building's technical systems. In the case of housing ventilation systems, the minimum requirements shown in Table 4 must be met.

Table 4- Specific fan capacity of ventilation systems in Austrian standard (OIB, 2014).

	specific capacity PSFP in W/(m³/s)		
	inlet air, air-conditioned	**inlet air, ventilation system**	**exit air**
single device	< 500	< 500	< 500
single-family house, multi-family house without central ventilation system	≥ 500 to 750	≥ 500 to 750	≥ 500 to 750

Within the scope of energy certifications, Austria has the Energy Performance Certificates (EPC) requirements. Since 2006 it has been mandatory to issue this certificate when purchasing or renting a unit in a residential or non-residential building at the stage of applying for the building permit. The Federal Energieausweis-Vorlage-Gesetz (EAVG) requires an EPC to be supplied or presented (OIB, 2014).

Each province has different EPC formats as well as specific indicators used to label the building. For the labelling scale, OIB presents four indicators, being the (useful) heating space demand (HWB) in kWh/m².year; primary energy demand (PEB) in kWh/m².year for residential buildings, and kWh/m³.year for non-residential buildings; CO2 emissions in kg/m².year; and finally, total energy efficiency factor fGEE. In total, nine labelling categories are presented, ranging from G (lowest ranking) to A++ (highest ranking). The limit value for each labelling category are shown in Table 5 (OIB, 2014).

Table 5- Energy label scale in Austria (OIB, 2014).

Label	**$HWB_{Ref.SK}$ [kWh/m².year]**	**PEB_{SK} [kWh/m².year]**	**CO_{2SK} [kg/m².year]**	**f_{GEE}**
A++	10	60	8	0.55
A+	15	70	10	0.7
A	23	80	15	0.85
B	50	160	30	1
C	100	220	40	1.75
D	150	280	50	2.5
E	200	340	60	3.25
F	250	400	70	4
G	> 250	> 400	> 70	> 4.00

Other reference values to be emphasized are related to the inspection of heating and air-conditioning systems. In Table 6 the regulatory structure according to the Austrian provinces is provided.

Table 6- Regulatory framework of Austrian provinces regarding the inspection of Heating and AC systems (OIB, 2014).

Province	**Heating Systems**	**AC Systems**
	Time Intervals	**Time Intervals**
Burgenland	1-year interval: < 50 kW old 2-year interval: > 50 kW old 3-year interval: < 26 kW new	3-year interval: > 12kW
Carinthia	diff. Intervals: > 20 kW according to the type of fuel	3-year interval: > 12kW 5-year interval: > 12kW
Lower Austria	3-year interval: between 6 and 50 kW 1-year interval: > 50 kW	5-year interval: > 12kW
Upper Austria	3-year interval: < 15 kW 2-year interval: between 15 and 50 kW 1-year interval: > 50 kW	1-year interval: > 50 kW 3-year interval: between 12 and 50 kW
Salzburg	diff. Intervals: > 20 kW according to the type of fuel	diff. Intervals: > 12 kW
Styria	1-5 year intervals: > 8 and > 50 kW according to the kind of fuel	1-year interval: > 50 kW 3-year interval: > 12kW 12-year interval: > 12kW
Tyrol	1-5 year intervals: according to the kind of fuel	5-year interval: > 12kW
Vorarlberg	2-4 year intervals: according to the kind of fuel > 100kW < 15-year interval: > 20kW	3-year interval: > 12kW
Vienna	1-year interval: > 50 kW 2-year interval: > 15 kW 5-year interval: > 15 and < 26 kW (gas)	3-year interval: > 12kW 12-year interval: > 12kW

Furthermore, developed by the Federal Ministry of Science, Research and Economics together with the nine Austrian states, the Austrian National Energy Efficiency Action Plan (NEEAP) is presented, which describes the way to increase energy efficiency and standardise energy efficiency regulations in the country by the end of 2020.

The plan also foresees increasing demand for energy-efficient services, reducing energy consumption and, at the same time, fighting energy poverty by avoiding nuclear energy. Not only that, but the government also sets a good example to the population by accelerating the implementation of energy efficiency in public buildings. By these actions, the government intends to reduce energy consumption by 20% in relation to 2007 (NEEAP, 2007).

Among the measures for the residential building sector, the following categories stand out:

- Subsidies for residential buildings (e.g. a rehabilitation grant such as the "Sanierungscheck" or Rehabilitation check);
- District heating grants (e.g. for the installation of a heat transfer station);
- Energy performance standards in building regulations.

4.3 Portugal

In December 2019, Portugal published in its national journal the approval of the National Energy and Climate Plan 2030 (PNEC 2030), which is the main instrument of national energy and climate policy for the next decade. According to the plan, the challenges are transformational and some determining aspects of life in society are faced, in particular with regard to production and consumption patterns, the relationship with energy production and use, and the way cities and living spaces are thought (PNEC, 2019).

On the energy efficiency dimension, the plan states:

> "Energy efficiency is one of the most important elements in achieving a transition to a carbon-neutral economy, while generating growth, jobs and investment opportunities. This is why energy efficiency is seen not only as an opportunity for development and modernisation, but also as the priority energy source, in the sense that energy which is not produced/consumed is the safest, cleanest, and cheapest energy. This vision is in line with Community policy, and the EU has defined "energy efficiency first" as one of the guiding principles of its energy policy." (PNEC, 2019)

Section A of Chapter 3 of the PNEC 2030, highlights the strategies for renovating the national building stock of residential and non-residential buildings, both public and private. In the meantime, the strategies for residential buildings will be presented for the focus of this work (PNEC, 2019).

The plan therefore intends to promote the energy renewal of the housing stock and the NZEB buildings. In short, the aim is to mobilize the necessary efforts to promote energy efficiency through the rehabilitation of buildings. According to the plan, rehabilitating and making buildings more efficient makes it possible to achieve several objectives, such as reducing the energy bill, reducing greenhouse gas emissions, and improving the level of comfort and health of users. In this way, the energy rehabilitation of buildings should be considered a priority in the country (PNEC, 2019).

To ensure an effective energy renewal of the building stock, the action measures are foreseen, such as updating the Energy Certification System for Buildings (SCE), making available a new version of the Energy Certificate and, finally, promoting NZEB buildings.

In the framework of the SCE update, and in the context of the transposition of Directive (EU) 2018/844 (amendment of Directive 2010/31/EU) of the European Parliament on the energy performance of buildings (EPBD), several purposes are presented, with emphasis on the registration and monitoring of actions carried out on buildings and their technical systems (PNEC, 2019).

In this context, in line with the new EPBD requirements, it is expected that the energy certification of buildings update will reinforce the integration of diverse information and should contribute to improving the material to be made available to the consumer, through accessible and transparent means of advice, including and preferably digital platforms, but also secondary options such as support desks or platforms that aggregate the supply and demand of solutions for improving energy performance, the implementation of renovation passports or platforms for registering interventions related to buildings and impacting on energy performance (PNEC, 2019).

With regard to the new version of the Energy Certificate and considering the new requirements of the European Union Directive, it is recommended that the importance of the Energy Certificate for Buildings should be reinforced. To this end, the new energy certificate will present a language that is more accessible to the citizens, which will allow them to create a better perception of the characteristics and performance of their buildings, such as the level of comfort indicators, thus fulfilling the main function of creating an energy efficient policy for buildings (PNEC, 2019).

The new certificate will also present the way to be followed if improvement measures are to be implemented, and the impact of these improvements. The planning and prioritization of these measures will be established with the strategy to be taken in cases of rehabilitation, initially considering a reduction in energy needs, and only then implementing at the level of technical systems including the use of renewable energy (PNEC, 2019).

Among the expectations of the new update of the energy certificate, the support for the evaluation of the energy performance of buildings and the requirements for rehabilitation is reinforced, in a way adapted to the new European legislative context. It is also worth mentioning that the SCE will serve as a support for the identification of the conditions of the existing buildings and the needs for improvement, and subsequently, monitoring and validating the implementation of energy performance improvement measures (PNEC, 2019).

Lastly, the plan aims to promote the implementation of the NZEB concept in buildings by means of a realistic strategy appropriate to the climate, cultural and economic reality of the country. By establishing a new paradigm, the NZEB concept will be promoted by the main agents of the construction sector, in order to disseminate a portfolio of technical solutions that allow new and existing buildings to gradually reach the NZEB level. In the case of existing buildings, guidelines and support for the rehabilitation project should be established that promote the monitoring of consumption, the implementation of efficient and durable equipment and, finally, the optimization of consumption in a sustainable way (PNEC, 2019).

In this context, it is worth mentioning the regulations established in consecutive decrees of law published in the government journal over the last decade, which not only define the concepts of NZEB, but also present reference values demanded for the building to meet minimum energy efficiency requirements.

In short, the definition of NZEB buildings in the Portuguese context is presented in Ordinance No. 42/2019, and in accordance with Decree Law No. 118/2013, the benchmarks are established in the Energy Performance Regulation of Housing Buildings (REH).

Thus, the law defines NZEB buildings as:

> “Buildings characterised by a very high energy performance, and have almost zero or very small energy needs, covered to a large extent by energy from renewable sources, whether produced on site or nearby." (DRE, 2019).

Unlike in Austria, the reference values for residential buildings are presented in a more complex way, as the REH establishes a separation by climate zones, three winter and three summer climate zones, as shown in figure 11. In addition, the regulation also sets its minimum values categorically by analysing the structures and systems of the building separately.

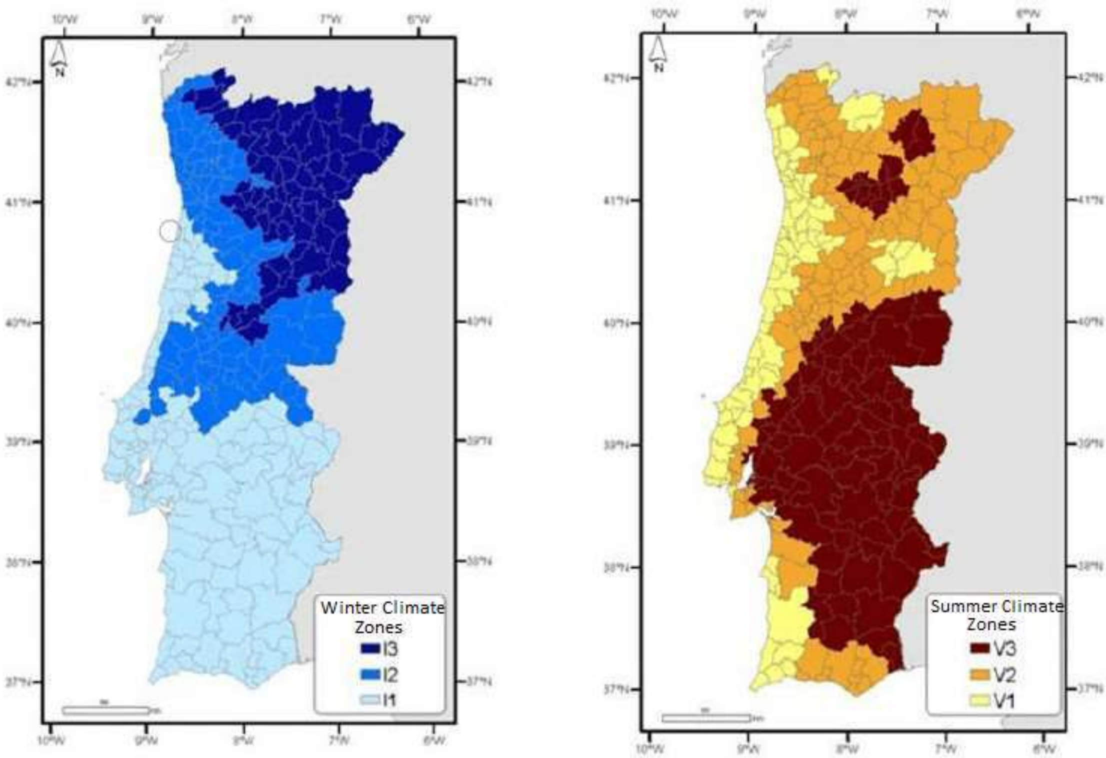


Figure 11- Portugal Climate Zones according to the REH (RCCTE, 2006).

The Ntc indicator [$kWh_{EP}/(m^2.a)$] characterises the value of the building's primary energy needs related to the regulated uses of heating, cooling, sanitary hot water production and, if available, mechanical ventilation. Unlike Austria, once again, this indicator does not have a minimum value, however, its variables have, which consequently limits its final value. The Nt indicator [$kWh_{EP}/(m^2.a)$], on the other hand, indicates the maximum value allowed for new buildings and major renovations this value depends on the date of construction of the building, referred on Table 7.

In summary, the regulation establishes the values of the nominal needs and limit ratios, for useful energy for heating, cooling and primary energy of buildings. (REH, 2013).

Table 7- values of the nominal needs and limit ratios, for useful energy for heating, cooling and primary energy of buildings (REH, 2013).

Year of Construction	Nic/Ni	Nvc/Nv	Ntc/Nt
Before 1960	Not applicable	Not applicable	1,50
Between 1960 and 1990	1,25	1,25	1,50
After 1990	1,15	1,15	1,50

Thus, the ratio between Ntc and Nt, called Rnt, represents the energy class of the residential buildings. Thus, the Dispatch n º 15793-J/2013 (DRE, 2013) presents the Rnt value ranges for determining the energy class in SCE certificates (Table 8).

Table 8- Rnt value intervals for the determination of the energy class in SCE certificates of model type housing (DRE, 2013).

Energy Class	Rnt Value
A+	Rnt ≤ 0,25
A	0,26 ≤ Rnt ≤ 0,50
B	0,51 ≤ Rnt ≤ 0,75
B-	0,76 ≤ Rnt ≤ 1,00
C	1,01 ≤ Rnt ≤ 1,50
D	1,51 ≤ Rnt ≤ 2,00
E	2,01 ≤ Rnt ≤ 2,50
F	Rnt ≥ 2,51

One of the most important aspects for the analysis of the energy efficiency of a building refers to the thermal quality of its envelope. According to the Portuguese regulations, the construction elements and solutions of buildings exposed to the intervention must be properly characterized in terms of their thermal behaviour or the technical characteristics that may determine or affect this behaviour.

Thus, the REH establishes the reference values for the maximum thermal transmission coefficients of the opaque and glazed spans elements $U_{\text{máx}}$ [W/(m^2 .°C)], values that are distinguished by winter climate zone. Table 9 shows the update of the values presented in the regulation, in accordance with Ordinance No. 379-A/2015. Due to the focus of this study, only the values of the climate zones of continental Portugal will be presented.

Table 9- Maximum permissible surface thermal transmission coefficients of opaque and glazed spans elements, Umax [W/(m^2.°C)] (DRE, 2015).

Umáx [W/(m2 .°C)		**Climate Zone**		
		I1	**I2**	**I3**
Current area of the enclosure in contact with the exterior or with non-useful spaces with loss reduction coefficients btr> 0.7	Vertical elements	0.50	0.40	0.35
	Horizontal elements	0.40	0.35	0.30
Glazed spans (Uw)		2,80	2,40	2,20

In the meantime, Portugal has in recent years presented numerous programmes that encourage the rehabilitation of existing buildings, and Ordinance No. 297/2019 of 2019 establishes the thermal transmittance coefficients for these cases. Table 10 presents the values for walls, roofs, external pavements and glazed spans (DRE, 2019).

Table 10- Maximum permissible surface thermal transmission coefficients of opaque and glazed spans elements for buildings to be rehabilitated Umax [W/(m^2.°C)].

<table>
<tr><th colspan="5">Maximum permissible surface thermal transmittance coefficients Umáx [W/(m2 .°C)]</th></tr>
<tr><th colspan="2">Exterior Element</th><th>I1</th><th>I2</th><th>I3</th></tr>
<tr><td colspan="2">Vertical Opaque Elements - Walls</td><td>1.70</td><td>1.50</td><td>1.40</td></tr>
<tr><td rowspan="2">Opaque Horizontal Elements</td><td>Roofs</td><td>0.80</td><td>0.70</td><td>0.60</td></tr>
<tr><td>Outdoor pavements</td><td>1.00</td><td>0.90</td><td>0.80</td></tr>
<tr><td colspan="2">Glazed spans (doors and windows)</td><td>4.50</td><td>4.00</td><td>4.00</td></tr>
</table>

According to Ordinance no. 379-A/2015 of 22 October, all areas of any external opaque element that constitute a flat thermal bridge area (PTP), namely pillars, beams, shutter boxes, must have a thermal transmission coefficient (U_{ptp}) value, calculated in a one-dimensional manner in the normal direction of the surroundings, not exceeding 0.9 W/(m2 .°C)

Finally, still in the field of thermal quality of the envelope, the Portuguese regulation foresees that in case of glazed spans where the sum of their areas is greater than 5% of the area of the compartment served by it, and not oriented in the north quadrant inclusive, they must present a maximum global solar factor (g_{Tmax}) according to Table 11. The method of calculating the global factor is expressed in detail in topic 2.3 of the REH.

Table 11- Maximum permissible solar factors of glazed spans, gTmáx (REH, 2013).

<table>
<tr><th>g_{tmax}</th><th colspan="3">Climate Zone</th></tr>
<tr><td>inertia class</td><td>V1</td><td>V2</td><td>V3</td></tr>
<tr><td>weak</td><td>0,15</td><td>0,10</td><td>0,10</td></tr>
<tr><td>medium</td><td>0,56</td><td>0,56</td><td>0,50</td></tr>
<tr><td>strong</td><td>0,56</td><td>0,56</td><td>0,50</td></tr>
</table>

Lastly, it is presented the Despatch no. 15793-D/2013, which proceeds emphasizing the conversion values between useful energy and primary energy to be used in determining the annual nominal needs of primary energy.

In this way, the dispatch predetermines the conversion factors between final energy and primary energy to be used to establish the annual nominal needs of primary energy of residential buildings.

Thus, the conversion factors are F_{pu} = 2,5 kWh_{EP}/kWh for electricity, regardless its origin, and F_{pu} = 1,0 kWh_{EP}/kWh for non-renewable solid, liquid and gaseous fuels. For thermal energy from renewable sources, the conversion factor also presents a value equal to 1,00 kWh_{EP}/kWh.

4.4 Brazil

In 2001 the government created Law 10,295 to induce energy efficiency in Brazil, which later became known as the “Energy Efficiency Law”. As one of the first actions conceived by the Brazilian government, it had the understanding that energy conservation should be a topic of the National Energy Policy, and began to stimulate the development of new technologies, in addition to bringing into focus the preservation of the environment and the introduction of more efficient products in the Brazilian market (Planalto, 2001).

In the last decade, the Ministry of Mines and Energy (MME) has developed the Energy Efficiency Plan (PNEF) in order to synthesize the various energy efficient initiatives in Brazil. The plan also focuses on facilitating the use of resources and allowing for integrated action among the various agents in each of the areas with potential energy-efficient solutions (PNEF, 2011).

In this manner, one of the topics developed by PNEF makes reference to the buildings. It aims to cover the potential for reducing electricity consumption, in addition to presenting the regulations and strands in this area. According to the plan:

> “The adoption of a policy of energy conservation is fundamental, since it allows the reduction of primary energy necessary to provide the same level of useful energy consumption and allows the construction of a development style that implies less energy demand, through the use of alternative solutions and new technologies” (PNEF, 2011).

PNEF also highlights the value of the construction process that presents passive solutions to promote the comfort of the users, in order to reduce the need for extra use of resources in the lighting and air conditioning systems. The relevance of the PROCEL, national program of electric energy conservation, is also emphasized, which aims to meet the need to increase efficiency in the final uses of energy, working on the demand of electricity (PNEF, 2011).

Below, Figure 12 presents the PROCEL Stamp, issued in all fields of energy efficiency in Brazil.

Figure 12- PROCEL Label (PNEF, 2011)

After an energy crisis in the country, in partnership with the MME and also with INMETRO (National Institute of Metrology, Quality and Technology) PROCEL created a sub-programme directed only to buildings, called "Procel Edifica". The program estimated a potential consumption reduction of approximately 30% with the implementation of energy efficiency actions in the lighting systems, air conditioning and architectural interventions in the envelope concerning the existing buildings (PNEF, 2011).

Since its creation, Procel Edifica has been active in the development of energy conservation projects in residential, commercial, service and public buildings, such as support to the production of new technologies, materials and construction systems to be used in buildings (PNEF, 2011).

Also, in partnership with the MME and INMETRO, within the scope of energy certification, the Technical Quality Regulation (RTQ) for the Energy Efficiency Level of Residential Buildings was created, a voluntary labelling system for the energy efficiency level of buildings. The last regulation was published in Ordinance nº 18/2012 and defines the reference values for a building to receive the certificate corresponding to its energy efficiency level.

Figure 13 shows the example of the Procel Edifica stamp, issued by Inmetro, which determines the level of efficiency of buildings.

Figure 13 Example of energy certificate for residential buildings (RTQ, 2012).

In the case of autonomous housing units, as well as in single-family buildings, the requirements concerning the thermal performance of the housing, the efficiency of water heating systems (when applicable) and any bonus related to initiatives that increase the efficiency of the building are evaluated.

A building will be certified, according to the obtained final score. It can be awarded with a level that varies from A (most efficient) to E (least efficient). The efficiency level of each requirement is also equivalent to a corresponding number of points, assigned according to Table 12 (RTQ-R, 2012).

Table 12- Numeric Equivalent for each level of efficiency (RTQ-R, 2012).

Efficiency Level	Numeric Equivalent
A	5
B	4
C	3
D	2
E	1

However, in some analysed items, instead of a numerical equivalent, there is a scale score, as presented in Table 13.

Table 13- Classification of the efficiency level according to the score obtained (RTQ-R, 2012).

Efficiency Level	Scoreboard
A	$PT \geq 4{,}5$
B	$3{,}5 \leq PT < 4{,}5$
C	$2{,}5 \leq PT < 3{,}5$
D	$1{,}5 \leq PT < 2{,}5$
E	$PT < 1{,}5$

Thus, the regulation presents the classification of the level of efficiency (PT) of autonomous housing units (UHs) as the result of the distribution of the weights in the equation below, using the coefficient, a, presented in Table 14, according to the geographical region in which the building is located (RTQ-R, 2012).

$$PT_{UH} = (a * EqNumEnv) + [(1 - a) * EqNumAA] + Bonus \qquad (1)$$

Where PT_{UH} represents the total score of the efficiency level of the autonomous housing unit; EqNumEnv is the numerical equivalent of the thermal performance of the housing unit envelope when naturally ventilated; and finally, EqNumAA represents the numerical equivalent of the water heating system. Bonus, on the other hand, are scores attributed to initiatives that increase the efficiency of the building (RTQ-R, 2012).

Table 14- Coefficients according to the geographical region (RTQ-R, 2012).

Coefficient	Geographic Region				
	North	Northeast	Midwest	Southeast	South
a	0,95	0,90	0,65	0,65	0,65

Within the housing units, the regulation describes the criteria to evaluate the performance of the building envelope. Among the envelope requirements, the reference values of thermal transmittance, thermal capacity and solar absorption of the external walls and roof must be met according to the Bioclimatic Zone in which the building is located (RTQ-R, 2012).

As mentioned in the previous chapter, Brazil has great bioclimatic diversity due to its magnitude. The reference values considered in the calculation of the energy efficiency of the building, the zoning presented by the Brazilian Association of Technical Standards (ABNT) is used, which divides the country into 8 bioclimatic zones, as seen in Figure 14.

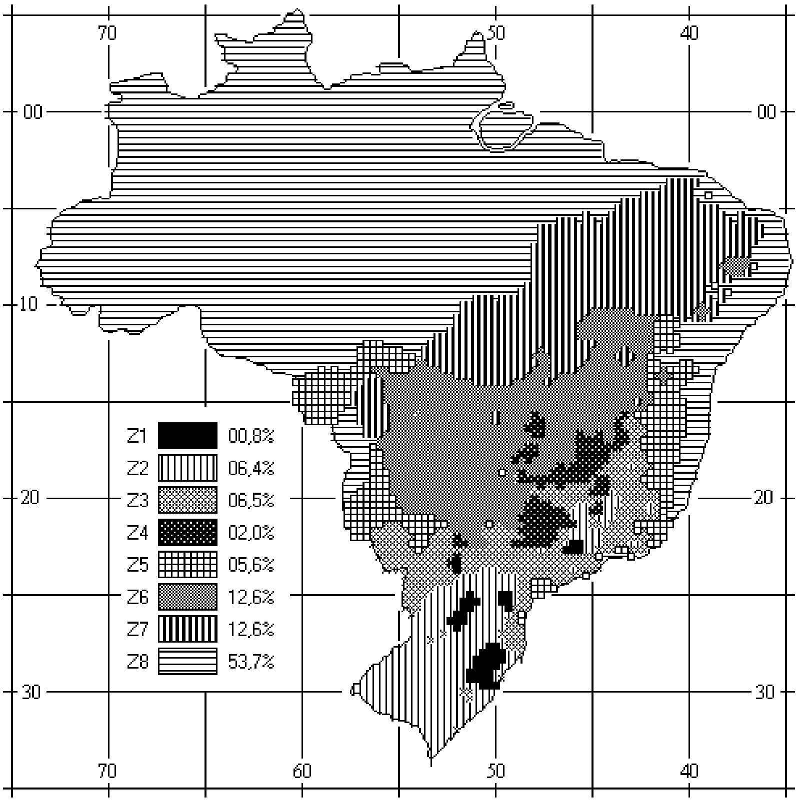


Figure 14- Brazilian bioclimatic zoning (ABNT, 2003).

Therefore, considering the bioclimatic zones presented in Figure 14, the table below (Table 15) presents the reference values for walls and roof, for solar absorption (α), thermal transmittance (U), and thermal capacity (CT).

Table 15- Solar absorbance, thermal transmittance and thermal capacity requirements for the different bioclimatic zones (RTQ-R, 2012).

Bioclimatic Zone	Component	Solar Absorption (dimensionless)	Thermal Transmittance [W/(m²K)]	Thermal Capacity [kJ/(m²K)]
ZB1 and ZB2	Walls	No requirement	U ≤ 2,50	CT ≥ 130
	Roof	No requirement	U ≤ 2,30	No requirement
ZB3 to ZB6	Walls	α ≤ 0,6	U ≤ 3,70	CT ≥ 130
		α > 0,6	U ≤ 2,50	CT ≥ 130
	Roof	α ≤ 0,6	U ≤ 2,30	No requirement
		α > 0,6	U ≤ 1,50	No requirement
ZB7	Walls	α ≤ 0,6	U ≤ 3,70	CT ≥ 130
		α > 0,6	U ≤ 2,50	CT ≥ 130
	Roof	α ≤ 0,4	U ≤ 2,30	No requirement
		α > 0,4	U ≤ 1,50	No requirement
ZB8	Walls	α ≤ 0,6	U ≤ 3,70	No requirement
		α > 0,6	U ≤ 2,50	No requirement
	Roof	α ≤ 0,4	U ≤ 2,30	No requirement
		α > 0,4	U ≤ 1,50	No requirement

In the field of water heating systems, RTQ describes the criteria for evaluating the efficiency of systems, determining appropriate reference values for hot water pipes insulation, which must also be suitable for their intended conduction function and must comply with applicable product technical standards (RTQ-R, 2012).

Thus, in Table 16 the minimum insulation thickness of pipelines for water heating is presented.

Table 16- Minimum insulation thickness of pipelines for water heating (RTQ-R, 2012).

Water temperature (ºC)	**Thermal conductivity (W/mK)**	**Nominal pipe diameter (mm)**	
		< 40	≥ 40
T ≥ 38	0,032 a 0,040	1,0 cm	2,5 cm

The regulation also specifies that there are different ways to apply water heating systems as well as solar heating, gas heating, heat pumps, oil boilers and finally electric heating. There are also cases of mixed heating systems, which the efficiency level is the combination of the water heating demand percentages of each system multiplied by its respective numerical equivalent specified in the regulation.

For the case study presented in the following chapter, the most common use is in the region of electrical heating in shower systems. In this case, the efficiency level is determined by the power of each product, according to the Inmetro system.

With regard to bonuses, initiatives that increase the efficiency of the UH may receive up to 1 point in the general classification of the UH added to the points obtained for each action. Among some examples of bonuses, can be mentioned those related to natural ventilation (varies from 0 to 0.4 points), natural lighting (varies from 0 to 0.3 points), artificial air conditioning (varies from 0 to 0.2 points), among others.

4.5 Summary

It can be noticed that although Austria and Portugal are member countries of the European Union, which must follow the directives proposed by the Union, they have different approaches to the application of standards for energy efficiency in buildings. Brazil, on the other hand, is a step behind in relation to the requirements for energy efficiency in buildings. Even though it presents criteria to be followed, they are not mandatory by law, which reduces the frequency with which they are applied in practice.

It can also be observed that while in Austria there is a great concern regarding the heating of the buildings, in Portugal there is a concern regarding both heating and cooling, due to the climatic zone in which it is located.

Finally, the complexity of the criteria to be considered must be emphasized. Both Austria and Portugal have simpler calculation systems, which makes it more accessible to construction professionals who intend to execute energy rehabilitation projects in buildings. The Brazilian criteria, on the contrary, are quite complex, which reduces even more their use in rehabilitated buildings in the country.

Chapter 6 of this work will provide a more detailed comparative analysis between all the legislations and energy certifications referred to in this chapter, in order to accomplish the objectives of this study.

Chapter 5

Case Studies

5. CASE STUDIES

In order to achieve the objectives proposed in this work, three different case studies will be considered. The first one is located in Kitzbühel, Tyrol, Austria. All the information related to this specific project, was essentially obtained from the project under development by David Manzl.

The second case study is located in the city of Vila Real, in the district of Vila Real, Portugal. It was once a typical single-family residence; however, its use has changed over the years.

Finally, the third case study is located in the city of Goiânia, in the state of Goiás, Brazil. Built in the 80's, it is a typical single-family residence of its time.

In Table 17 the main information of each of the above-mentioned is presented.

Table 17- Factbox buildings in Kitzbühel, Vila Real and Goiânia.

	Kitzbühel	**Vila Real**	**Goiânia**
AREA	127 m²	345 m²	324 m²
VOLUME	318 m³	1253 m³	1073 m³
CONSTRUCTION METHOD	heavy	heavy	heavy
HEATING	oil, radiators	radiators	none
COOLING	none	none	none
VENTILATION	window	natural/window	natural/window
ENERGY CONSUMPTION	H: 30000 kWh/a E: 5000 kWh/a	no data available	H: 0.00 kWh/a E: 2900 kWh/a

With tools developed in the Tecknikum Wien, the heating and cooling load were calculated. The heating load tool enables the user to enter the climate data of the location where the building is placed, so it can be used for different climate zones. The ratings presented by the tool do not correspond to the most current versions of the existing energy certificates, but with the results of the calculated values it is possible to create a relationship with the current required values, thus obtaining the current rating of the building. The cooling load tool, on the other hand, does not provide classifications, so its results will be used to relate to the certificates standards when necessary.

5.1 Kitzbühel, Austria

The first case study is located in Kitzbühel, Tyrol, Austria. It consists of a detached house built in 1974, and in the last decade has been used as a winter holiday home for tourists, given that it is 10 minutes away from a skiing slope. The house has only one ground floor and an area of 127 m². The current owners' rehabilitation proposal is to build a second floor, in addition to adapting layers to fit the standards of U-Values of a Plus-Energy-Building. Also, it is proposed to change the heating system from oil to a renewable energy and to investigate the possibility of use PV-panels.

In Figure 15 a photo of the southwest facade of the building is shown. It is possible to see that there are no buildings in the surroundings that can create any type of shading in the building, however, there is vegetation in the vicinity, which can influence this aspect.

Figure 15-Picture of the House in Kitzbühel (Manzl, 2020).

The house is divided into two separate apartments. The largest of them, with 85.5 m², has a living room, a kitchen, an office, an ensuite bedroom and a toilet, besides the circulation area.

The smallest, with an area of 41.8 m², has a living room and kitchen in an open concept, a bedroom, a bathroom and a hall. There is also a hallway common to both apartments.

Figure 16 presents the Floor Plan of the ground floor.

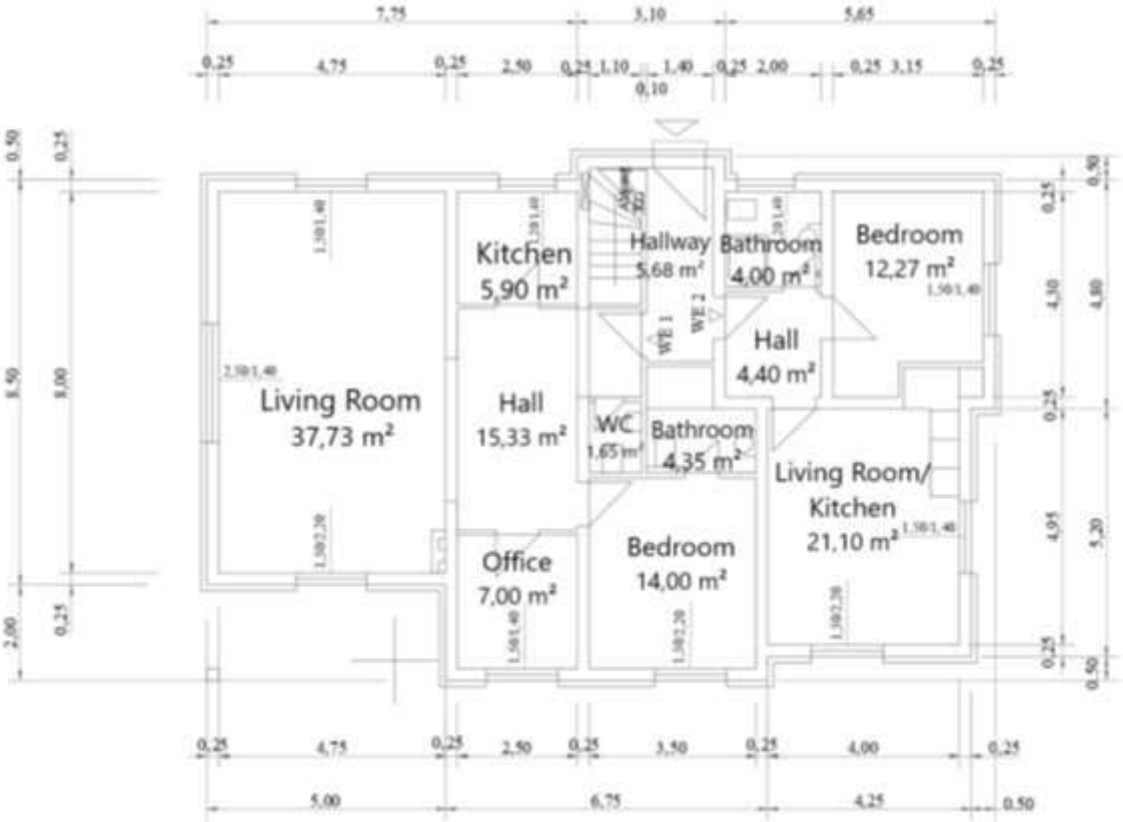


Figure 16- Ground Floor Plan of the House in Kitzbühel (Manzl, 2020).

Underneath these apartments, there is cellar with different functions, such as storage, private craftsmanship and a small office. In addition, the heat pump and the oil tank are also situated in the cellar. Above these apartments there is an unheated attic used for storage.

The energy bills provided by the owners show a heating and water heating expenditure of 30000 kWh/a and an electricity expenditure of 5000 kWh/a.

5.1.1 Construction Elements

The thermal shell is around the ground floor. The construction elements that will be studied are four: the external walls, the ceiling to the unheated attic, the floor to the basement and the windows.

There is no documented data regarding the materials used in the construction elements, for this reason the "Passivhaus Bauteilkatalog Sanierung" (IBO - Österreichisches Institut für Baubiologie und -ökologie 2017) is used to get a general idea of the U-values of the different layers.

In Table 18 the current thermal transmittance values of the mentioned elements are shown. In Figure 17 a schema of the house with the U-values considered are presented.

Table 18- U-Values of the Building in Kitzbühel.

Layers	U-Values
Outer Wall	0,219
Ceiling to the unheated Attic	0,319
Floor to Basement	0,983
Windows	1,5

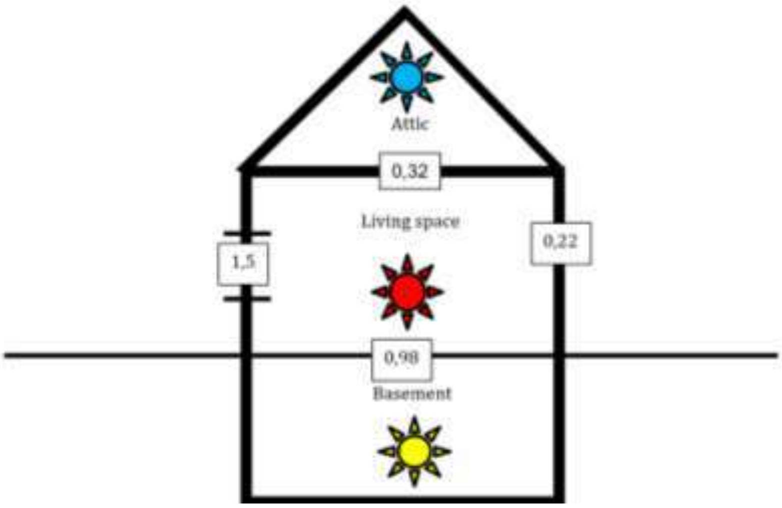


Figure 17- Overview of the U-Values of the Building in Kitzbühel.

These values were used in the calculations of the heating loads of the building before rehabilitation. The values show which elements of the building must be changed in order to the building become energy efficient. It is important to emphasize that for this building it is not necessary to make calculations for the cooling season, taking into account the studies made of its climate zone.

Analysing the thermal transmittance values, it is possible to conclude that both windows and floor are not within the requirements imposed by the regulation, since both are higher than the maximum values imposed by OIB.

With this perception, it is already expected that the building studied cannot be awarded with s a high level of efficiency. Therefore, in the next topic the results of the heating demand calculation will be presented. They show, also the energy efficiency level of this building.

5.1.2 Heating Load

As mentioned at the beginning of the chapter, the heating load calculations were performed in a specific tool and are presented in the spreadsheet in Annex 1. The final results of the calculations are presented in Figure 18.

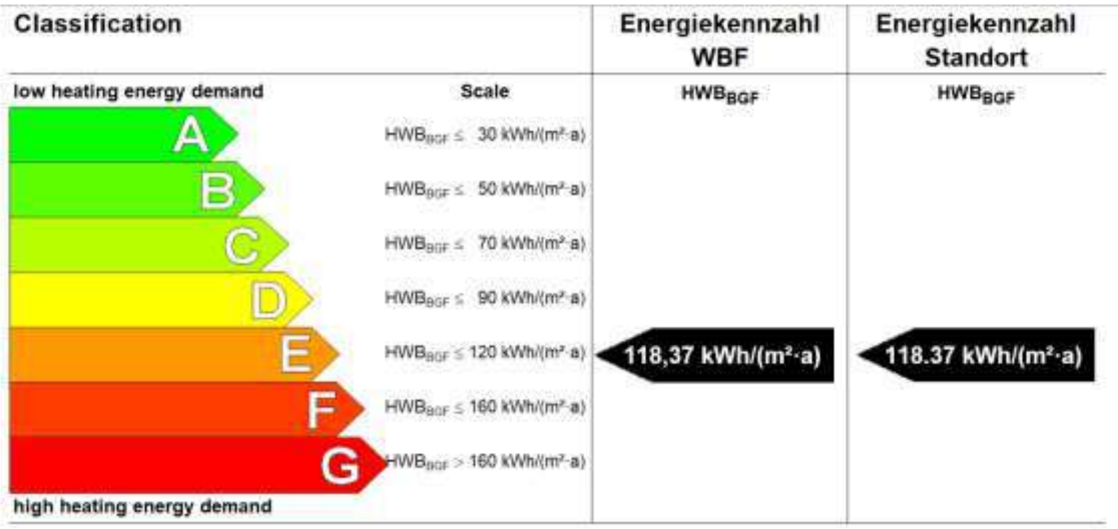


Figure 18- Heating Load Certificate of the Building in Kitzbühel.

The results show a relatively high heating demand, equal to 118.37 kWh/m²a. Considering the tool in which the calculations were performed, so the building is classified as level E. The higher classification (level A) has a low heating energy demand. In this case the heating demand should be ≤ 30 kWh/m²a.

However, as presented in chapter 4, the Austrian regulation has different values for certification. So, the value obtained in the calculations corresponds to level D, being the highest rating A++, for which the heating demand should be ≤ 10 kWh/m²a.

The house does not currently have an energy certificate because there is no obligation at the time of its construction. However, after the calculations performed, it has been concluded that a rehabilitation is necessary to reduce the building's energy demand. The certificate below provided by the tool (Figure 19) represents the current conditions of the building. It indicates the values of energy loss and gain, as well as the identification of the elements that must be changed in the rehabilitation, in order to obtain better results. As already predicted, considering the high U-values for the windows and the floor, it is possible to notice that there is a lot of transmission losses, which justifies the high value of the final result.

ENERGIEAUSWEIS (Energy certificate)

Climate data (location)

Elevation	760 m	Sums of irradiation I	
Heating days (HD)	259 d/a	South	575 kWh/(m²·a)
Standard-outside temperature θ_{ne}	-18 °C	East/West	362 kWh/(m²·a)
Mean indoor temperature θ_i	20 °C	North	210 kWh/(m²·a)
Heating degree days (HDD)	4,650 Kd/a	Horizontal	593 kWh/(m²·a)

Building data

Heated gross volume V_B	318.08 m³	Longitude (Geo. Länge)	12,3779
Area to outside A_B	395.61 m²	Latitude (Geo. Breite)	47,4529
Gross floor area BGF_B	127.23 m²		
Characteristic lenght l_c	0.80 m		

	Results	WBF	Location	
1	Conductances (Leitwerte) $L_e + L_u + L_g$	153.35	153.35	W/K
2	Added conductances $L_\psi + L_\chi$	11.11	11.11	W/K
3	Transmission conductance L_T	164.47	164.47	W/K
4	Ventilation conductance L_V	31.49	31.49	W/K
5	Heating load P_{tot}	7,446	7,446	W
6	Transmission losses Q_T	18,354	18,354	kWh/a
7	Ventilation losses Q_V	3,514	3,514	kWh/a
8	Passive solar gains $\eta \times Q_S$	4,483	4,483	kWh/a
9	Internal heat gains $\eta \times Q_i$	2,325	2,325	kWh/a
10	**Heating energy demand (Heizwärmebedarf) Q_h**	**15,061**	**15,061**	**kWh/a**
11	Ratio of heat gains and heat losses γ	32	32	%

Figure 19- Energy Certificate of the Building in Kitzbühel.

In a rehabilitation process that seeks the optimization of the values, should be indicated the replacement of the windows, with more efficient ones, with thermal transmittance coefficients much lower than the existing ones, this will decrease the value of transmission losses.

Another indication, which will also work in the building optimization process, is the application of thermal insulation below the floor in order to reduce the heat loss in this element of the building, since the building is in a place where the main climate characteristic is the low temperatures during most of the year.

5.2 Vila Real, Portugal

The second case study is located in the city of Vila Real, in the district of Vila Real, Portugal. Built in the beginning of the last century, it was once a typical single-family residence, however, its use has changed over the years. With a ground floor and 2 upper floors, the total area of construction is equal to 345 m² and the land area is equal to 156 m².

With the rehabilitation of the building, the owner intends not only to change the functionality of the building, but also to modernize it in order to meet the comfort requirements considered today. The aesthetics and structure are maintained as much as possible, but with the search for building quality there is a significant investment in energy efficient solutions.

In Figure 20 the main façade of the building, facing west, is shown. This building is located in the historical centre of the city, which justifies its ancient aesthetic. It is a terraced house, which means the openings (doors and windows) are only on the front and rear facades.

Figure 20- Front Picture of the Building in Vila Real, provided by the owners.

The ground floor is a commercial establishment with an area is 115 m², which has the shop area, a kitchen, a pantry and two toilets. In the outside area there is a garden.

Figure 21 presents the Floor Plan of the ground floor provided by the architect responsible for the rehabilitation design.

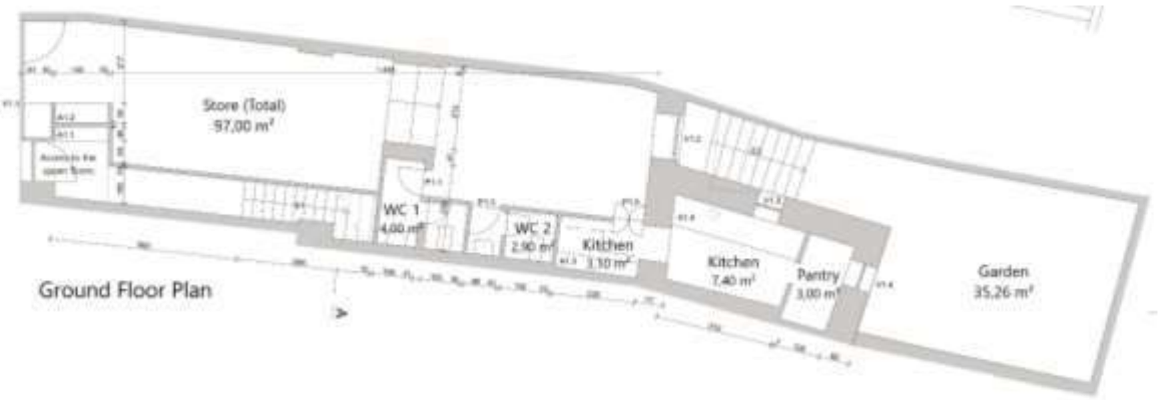


Figure 21- Ground Floor Plan of the Building in Vila Real.

The first and second floors are identical. Each of them has 115 m² of total construction and has two small apartments of about 40 m² and 56 m² each, besides the common circulation area. The smaller apartment has an open concept of bedroom, kitchen and living room, a bathroom, and an entrance hall. The larger apartment is similar, however there is a bedroom separate from the kitchen and living room.

In Figure 22 the Floor Plan of the first and second floors is shown.

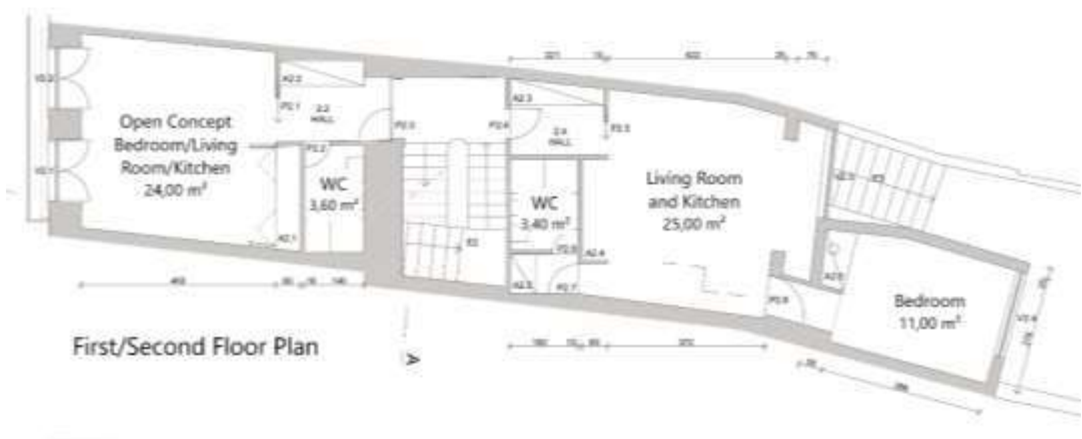


Figure 22-First Floor Plan of the Building in Vila Real.

The architect provided in the written document the data related to the building elements. As most of the construction of its time, the main structure is made of stone masonry walls however, the partition walls are made of "tabique" walls, which are made of a wooden structure, cross-linked, and filled and covered with an earthy material (i.e., simple earth or a plaster of earth and lime).

For the floors, the data provided does not describe the exact materials. Because of that, data representing the typical construction of the time was used. The ground floors were dirt or stone-clad paved, which could be covered with ceramic tiles or wood. On the upper floors, there was a wooden structure. In this construction solution, the floors have a structure made up of single piece wooden beams, which support directly on the resistant walls (Andrade, 2011).

The ceiling was made of a wooden slab in all its area. Above, there is a roof with wooden slats and ceramic tiles that partially cover it. Still in the building envelope, the windows are all double-glazed with wooden frames, although they are very old structures.

Even though the building has a water heating system, it has no central heating, nor air conditioning systems. However, the owners did not provide the energy bills that would show the water heating and the electricity expenditure.

5.2.1 Construction Elements

Because it is a building that has changed its typology over the years, the thermal shell should involve the ground floor, the first and second floors. The elements that will be studied in this project are five: the external walls, the ceiling to the attic, the roof, the ground floor and finally the windows.

The thermal transmittance values considered for the calculations will be considered according to the description of the construction elements and materials highlighted in the previous topic. In Table 19 the current U-values of the mentioned elements are shown. In Figure 23 a schema of the building with the U-values of the referred elements are presented.

Table 19- U-Values of the Building in Vila Real.

Layers	U-Values
External Wall	3,608
Ceiling to the Attic	1,023
Roof	1,012
Ground Floor	2,511
Windows	2,8

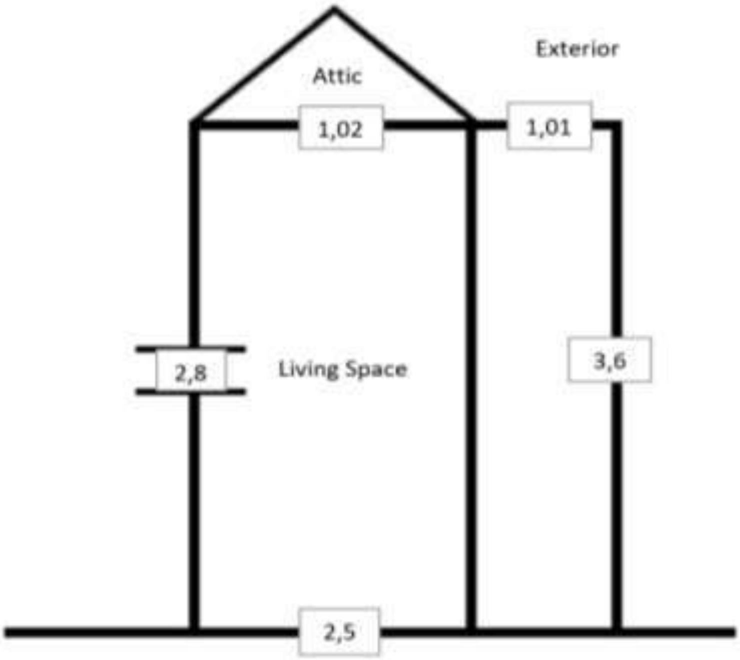


Figure 23- Overview of the U-Values of the Building in Vila Real.

In contrast to the house in Kitzbühel, this building in the historical centre of Vila Real has heating and cooling needs, taking into consideration the studies made of its climate zone. Therefore, the U-values were used in the calculations of the heating and cooling demand of the building. The results will highlight which building elements must be changed in order to make the building more energy efficient.

The building is located in the winter zone I3 and summer zone V2 established by the Portuguese regulations. Considering the thermal transmittance values of the elements referred to above, it is noticeable that the windows, the external walls and the floor have values above the maximum reference values imposed by the REH in that zone. Thus, it can be predicted that the calculations of the heating demand in winter and cooling demand in summer will show, in a certain way, an energy inefficient building.

5.2.2 Heating Load

The calculations of the heating load are shown in the spreadsheet in Annex 2. Below are the final results of the calculations (Figure 24). Although using an Austrian tool for the execution of the calculations, it allows the insertion of the climatic data of the studied location, in order to ensure that the result is consistent with the characteristics of the building presented.

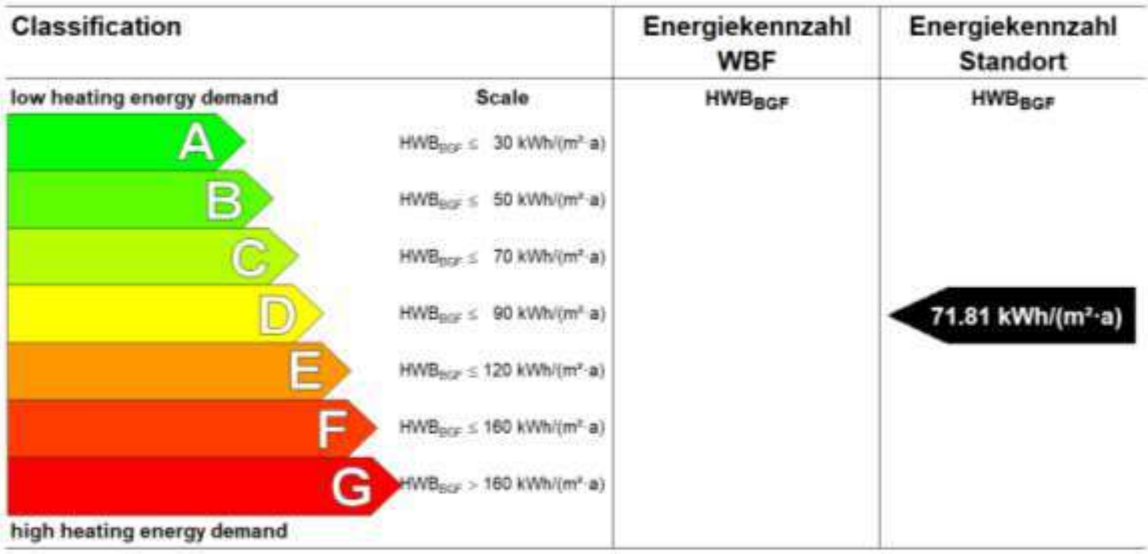


Figure 24- Heating Load Certificate of the Building in Vila Real.

Also as expected, the results show a relatively high value for heating demand, with the value equal to 71.81 kWh/m²a. According to the tool, the classification is rated as D, not considered a good rating for an energy efficient certificate. Actually, if applied to the Portuguese regulation, a D rating is extremely low, once the highest rate is class A+, 5 levels above the one obtained by the building.

Also, according to the tool used for the calculations, in Figure 25 the energy certificate for the building in Vila Real is shown, which points out the values of loss and energy gain. Thus, it is possible to identify which elements should be changed in the rehabilitation in order to obtain better results.

Such as the other building already referred in this study, it is possible to notice that there is a significant loss in transmissions. This result is a consequence of the high thermal transmittance values of the building elements.

ENERGIEAUSWEIS (Energy certificate)

Climate data (location)

Elevation	562 m	Sums of irradiation I	
Heating days (HD)	174 d/a	South	562 kWh/(m²·a)
Standard-outside temperature θ_{ne}	-2 °C	East/West	459 kWh/(m²·a)
Mean indoor temperature θ_i	20 °C	North	160 kWh/(m²·a)
Heating degree days (HDD)	2,143 Kd/a	Horizontal	485 kWh/(m²·a)

Building data

Heated gross volume V_B	1,144.25 m³	Longitude (Geo. Länge)	
Area to outside A_B	353.17 m²	Latitude (Geo. Breite)	
Gross floor area BGF_B	345.00 m²		
Characteristic lenght l_c	3.24 m		

	Results	WBF	Location	
1	Conductances (Leitwerte) $L_e + L_u + L_g$		649.19	W/K
2	Added conductances $L_\psi + L_\chi$			W/K
3	Transmission conductance L_T		649.19	W/K
4	Ventilation conductance L_V		113.28	W/K
5	Heating load P_{tot}		17,041	W
6	Transmission losses Q_T		33,395	kWh/a
7	Ventilation losses Q_V		5,827	kWh/a
8	Passive solar gains $\eta \times Q_S$		10,213	kWh/a
9	Internal heat gains $\eta \times Q_i$		4,236	kWh/a
10	**Heating energy demand (Heizwärmebedarf) Q_h**		**24,773**	**kWh/a**
11	Ratio of heat gains and heat losses γ		38	%

Figure 25- Energy Certificate of the Building in Vila Real.

Even if in different proportions, the building in Vila Real presents similar problems to the building in Austria that should be considered in a rehabilitation. The transmission losses value is very high, resulting from the high thermal transmittance values of the window elements, external walls and floor.

5.2.3 Cooling Load

The calculations of the cooling load are shown in the spreadsheet in Annex 3. For the calculations, it was used the construction method 1 (few thermal mass, external shading). The final results are presented in Table 20.

Table 20- Total cooling load calculations.

DESCRIPTION	GAINS (W)	GAINS/AREA (W/M²)
Irradiation Through Windows	715	12.6
Heat Transmission Through Windows	708	12.5
Heat Transmission from Outside Through Walls and Roofs	346	6.1
Heat Transmission from Adjacent Rooms, Attic, Stairways …	0	0
Heat Gains from People, Ambient Air, Under Consideration: 35 M³/H Per Person, 32°C, 14 G/Kg=17 G/M³	354	8.0
Heat Gains from Light and Electrical Devices	340	6.0
TOTAL COOLING LOAD	2563	45.2

As opposed to the other tool, this one does not provide the level of energy efficiency of the building, and as consequence, it is not possible to obtain the classification of the building. However, the previous tool provided the classification required for this case, while this one focuses on the heat transmissions that affect the comfort inside the building in summer days. As already identified in the heating load calculations, it is possible to recognise that windows are a major problem for the energy efficiency of the building, which is the main concern in an rehabilitation project.

As in the optimization of the house in Kitzbühel, it is then suggested to replace the windows with more modern and efficient ones. Not only this, but also the application of thermal insulating materials on walls in contact with the exterior, as well as on the floor in contact with the ground should be implemented. In this way, the building envelope is protected from transmission losses, which will reduce the energy demand for heating.

After rehabilitation, the building should be certified again, in order to verify its efficiency.

5.3 Goiânia, Brazil

The third case study is located in the city of Goiânia, in the state of Goiás, Brazil. Built in the 80's, it is a typical single-family residence of its time. With a ground floor and an upper floor, the total area of the construction is equal to 324 m² and the land area is equal to 790 m².

The owners want to transform the building, not only aesthetically, but also its functionality. In the last decades, there has been a great evolution in the technologies in the field of construction, mainly in energy and sustainability. The intention is to modernise the building by making it energy efficient through solutions that are suitable for the region's climate.

In Figure 26 the main façade of the house, facing south, is shown. It can be seen that there is a relevant amount of vegetation around the house. This is because the building is inside an ecological reserve in the southeast region of the city. Thus, its surrounding vegetation may have an impact on the thermal comfort of the house.

Figure 26- Front Picture of the House in Goiânia, provided by the owners.

The ground floor has an area of 225 m², which is divided into a garage, two large living rooms, an office, a toilet, a large kitchen with dining area, a service area (which includes a bedroom and a bathroom), a pantry, a terrace and a sauna. Outside, there is a swimming pool, an outdoor shower, a changing room, and a large garden.

In Figure 27 the Floor Plan of the ground floor provided by the architect is presented, including the external area (swimming pool, changing rooms and garden). It is also important to highlight that one of the living rooms (area equals 24,75 m²) has a double headroom.

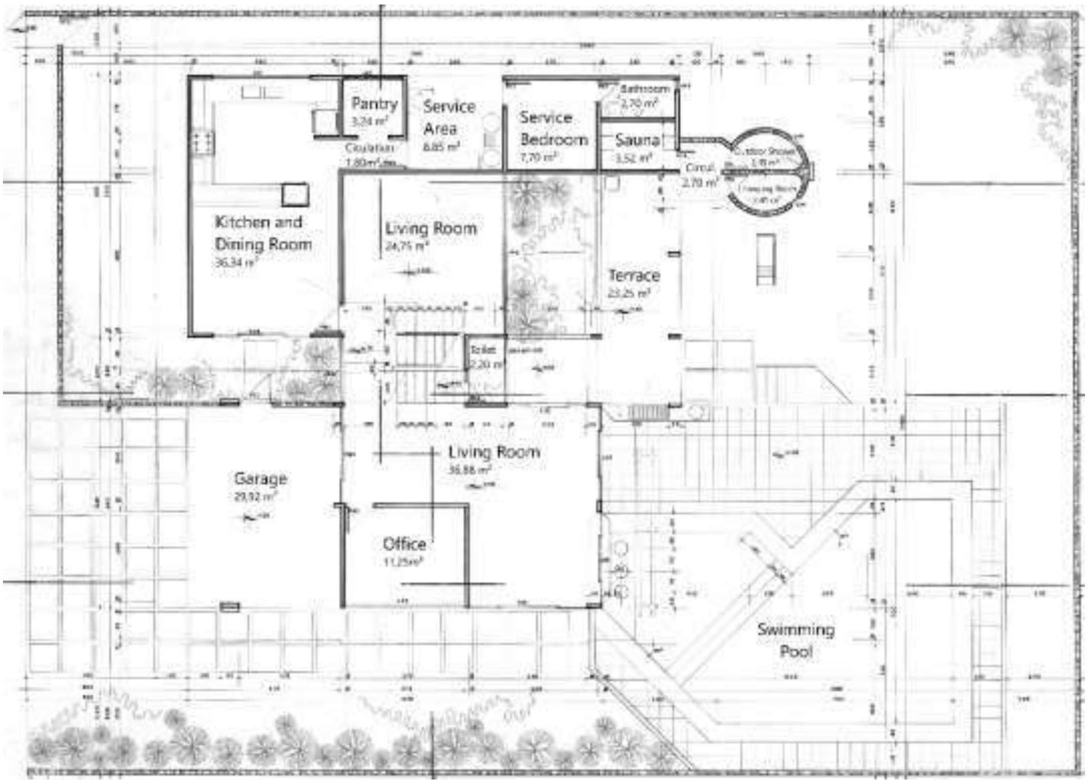


Figure 27- Ground Floor Plan of the House in Goiânia.

The first floor represents 98 m² of the total construction, divided into a TV room, two bedrooms, a bathroom, and an ensuite bedroom. In Figure 28 the Floor Plan of the first floor is shown.

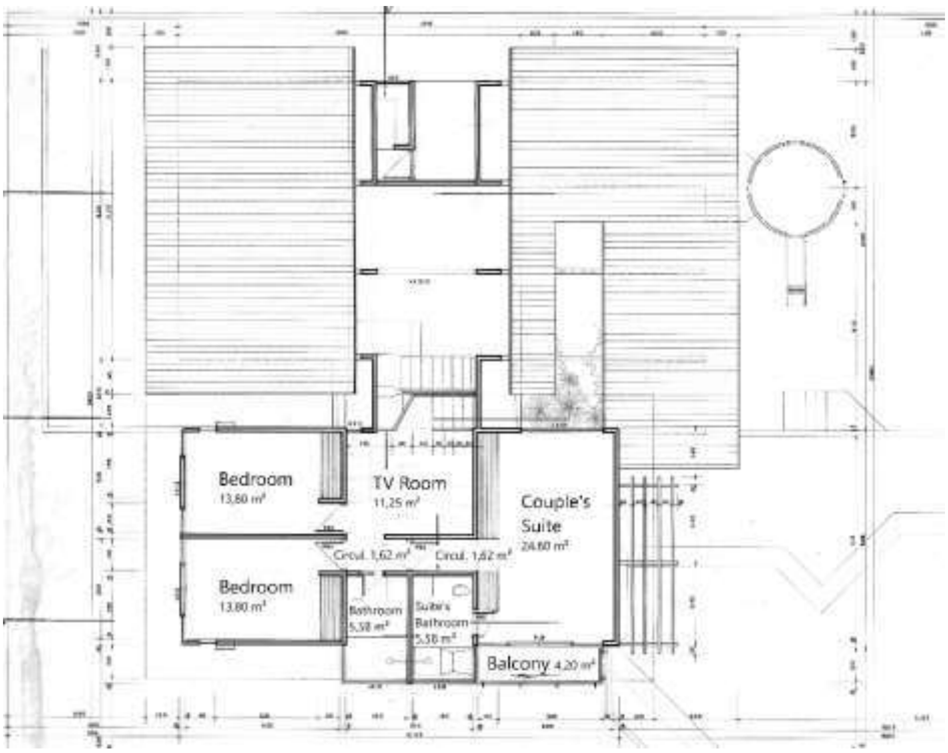


Figure 28- First Floor Plan of the House in Goiânia.

The data obtained from the descriptive memorial offered by the architect of the project shows that the building follows standards typical of the 1980s. The main structure is made of reinforced concrete and the walls are made of ceramic blocks for masonry (11.5x14x24 cm), covered with cement-based plaster and finally painted or ceramic coated.

As for the floor, the area in contact with the ground has a concrete layer of about 15 cm. The next layer is an 8 cm thick levelling layer that has the function of regularize the level of the entire area to receive the final layer, a 2 cm thick slate floor. On the upper floor, above the concrete slab there is also a counter floor, however, the final layer is made up of traditional ceramic coating.

The ceiling of the house has a sealed slab all over its area. Above it, there is a roof with wooden slats and ceramic tiles. Still on the building's envelope, the windows and doors are all single glazed, with 4 mm of thickness for the windows and 8 mm for the doors.

The house has no heating nor air conditioning systems. The showers are all electric, once there is the absence of water heating systems, something typical of the houses in this region of Brazil.

The energy bills provided by the owners show a heating and water heating expenditure of 0.00 kWh/a and an electricity expenditure of 2900 kWh/a, that includes the water heating.

5.3.1 Construction Elements

In order to determine cooling demand, the thermal shell should involve only the first floor, where the bedrooms are located. The elements considered in the cooling load calculations are the exterior walls, the roof and the windows.

For the calculations, the thermal transmittance of the windows considered was 5.8 W/m²K, since it is single glazed. As mentioned in the previous topic, the external walls are made of traditional ceramic blocks covered with plaster and paint. For this reason, the U-value used for calculations of heat transmission from outside to inside is equal to 2.2 W/m²K, a standard value for this type of material in Brazil.

In Figure 29 the rooms considered for the cooling load calculation are highlighted.

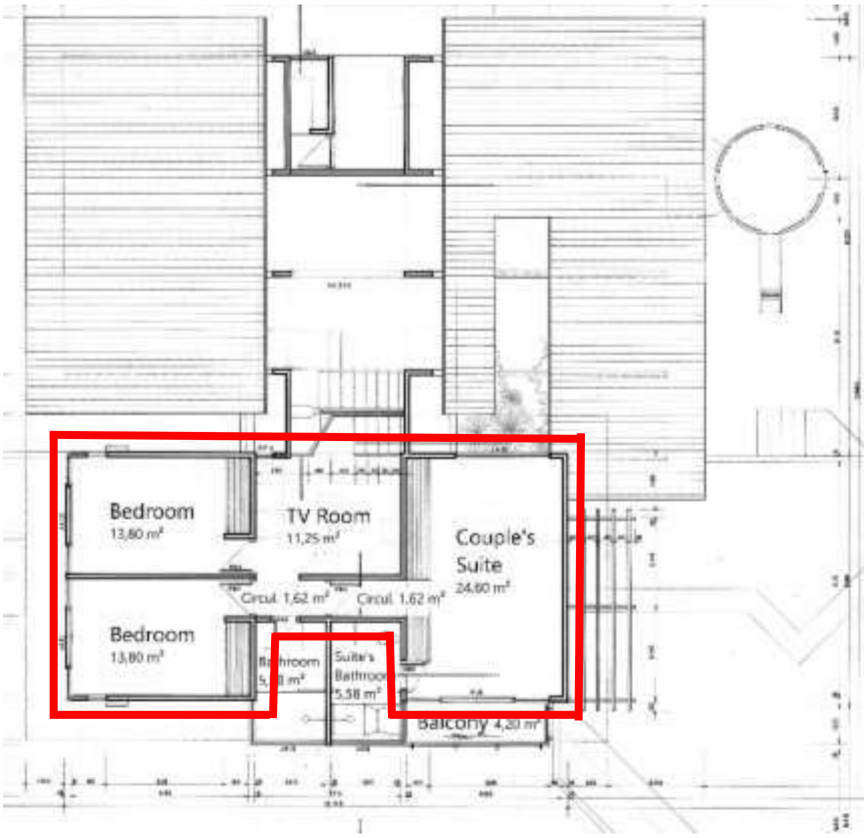


Figure 29- Thermal Shell used for Cooling Load Calculations.

5.3.2 Cooling Load

The calculations of the cooling load are shown in the spreadsheet in Annex 3. For the calculations, it was used the construction method 1 (few thermal mass, external shading), considering that there is shading influence in the vicinity of the building. The final results are presented in Table 21.

Table 21- Total cooling load calculations.

DESCRIPTION	GAINS (W)	GAINS/AREA (W/M²)
Irradiation Through Windows	356	6.3
Heat Trasmission Through Windows	366	6.5
Heat Transmission from Outside Through Walls and Roofs	5582	98.5
Heat Transmission from Adjacent Rooms, Attic, Stairways …	0	0
Heat Gains from People, Ambient Air, Under Consideration: 35 M³/H Per Person, 32°C, 14 G/Kg=17 G/M³	270	4.8
Heat Gains from Light and Electrical Devices	326	5.7
TOTAL COOLING LOAD	6900	121.7

For the calculation of the cooling load, the same Austrian tool was used, presented in the above-mentioned annex. However, this tool proved to be inefficient in the energy efficiency calculation of the building under study.

Among the facts that may show inconsistency is the fact that the tool used does not allow the insertion of climate data of the region where the building is located. Thus, the calculation is used based on a climate with temperatures between 24 and 26ºC, central European climate according to irradiation, ambient temperature, and humidity, which does not correspond to the reality of the site.

However, the calculations will be maintained in order to provide the values of heat transmission in the vertical, horizontal and window elements, which can be useful for the search of an optimization in the project.

As mentioned before, the tool does not provide the level of energy efficiency. The classification of the building is obtained according to the technical regulation of quality for the level of energy efficiency of Brazilian residential buildings.

The Annex 4 presents the calculations of Degree-Hour for cooling (GHr) in the bioclimatic zone 6. Some of the values used in the calculations, such as the value of the absorption coefficient and thermal capacity were taken from the Brazilian standard NBR 15220-2 (ABNT, 2015) and from the Manual a ZB6 of Procel Edifica, based on the ordinance nº 18/2012, respectively.

Thus, for the bioclimatic zone 6, the degrees-hour indicator is obtained by the equation below (Figure 30), using the constants presented in Table 22.

$$
\begin{aligned}
GH_R = {} & (a) + (b \times CT_{baixa}) + (c \times \alpha_{cob}) + (d \times somb) + (e \times solo \times AU_{amb}) \\
& + (f \times \alpha_{par}) + (g \times CT_{alta}) + (h \times PD/AU_{amb}) + (i \times Ab_S) + (j \times SomA_{par}) \\
& + (k \times solo) + (l \times CT_{cob}) + (m \times U_{cob} \times \alpha_{cob} \times cob \times AU_{amb}) + (n \times P_{ambL}) \\
& + (o \times AAb_S \times (1\text{-}somb)) + (p \times AU_{amb}) + (q \times F_{vent}) \\
& + [r \times (U_{cob} \times \alpha_{cob}/CT_{cob}) \times AU_{amb}] + (s \times A_{parInt}) + (t \times AP_{ambN} \times U_{par} \times \alpha_{par}) \\
& + (u \times P_{ambO}) + (v \times P_{ambN}) + (w \times AP_{ambS} \times U_{par}) \\
& + (x \times AP_{ambL} \times U_{par} \times \alpha_{par}) + (y \times AAb_L \times F_{vent}) + (z \times P_{ambS}) \\
& + (aa \times A_{parInt} \times CT_{par}) + (ab \times AAb_O \times (1\text{-}somb)) + (ac \times AAb_N \times F_{vent}) \\
& + (ad \times Ab_N) + (ae \times PD \times AU_{amb}) + (af \times AAb_S \times F_{vent}) \\
& + (ag \times AAb_O \times F_{vent}) + (ah \times AP_{ambO} \times U_{par} \times \alpha_{par}) + (ai \times CT_{par}) \\
& + (aj \times AAb_N) + (ak \times AAb_O) + (al \times AAb_S) + (am \times PD) + (an \times AAb_L) \\
& + (ao \times AP_{ambN} \times \alpha_{par}) + (ap \times AP_{ambN} \times U_{par}) + (aq \times AP_{ambN}) \\
& + (ar \times AP_{ambO}) + (as \times Ab_O)
\end{aligned}
$$

Figure 30- Equation that indicates the degree-hour for cooling of ZB6 (RTQ, 2012).

Table 22- Equation constants (RTQ, 2012).

a	2761.081	m	49.7464	y	353.082	ak	-158.339
b	3125.514	n	1146.875	z	825.5822	al	-141.757
c	3942.258	o	-199.963	aa	-0.0078	am	614.7558
d	-3602.93	p	85.3725	ab	49.9509	an	-80.6792
e	-28.7788	q	-2857.67	ac	431.5161	ao	-636.128
f	4083.277	r	16.0537	ad	-1237.02	ap	-205.499
g	-1291.11	s	28.1849	ae	-46.9272	aq	375.6431
h	2391.402	t	340.8291	af	338.6679	ar	-67.2184
i	-513.133	u	2184.36	ag	383.4189	as	-708.575
j	-0.4197	v	2581.42	ah	43.064		
k	-2285.28	w	15.9464	ai	0.4015		
l	-1.0075	x	61.7515	aj	-156.24		

After performing the calculations, the value of GHr equal to 69463.12 degree-hours was obtained, being an extremely high value, and, according to the numerical equivalent of the envelope and efficiency classification, obtaining a negative certification of 1 and E, respectively (Table 23). This shows the level of energy inefficiency of the building, a result of the construction policies at the time it was built.

Table 23- Numerical equivalent of the environment envelope - Bioclimatic Zone 6 (RTQ, 2012).

Efficiency	Eq.NumEnv	Condition
A	5	GHr ≤ 2745
B	4	2745 < GHr ≤ 5489
C	3	5489< GHr ≤ 8234
D	2	8234 < GHr ≤ 10978
E	1	GHr > 10978

The negative result was, in a way, expected. Since the Austrian calculation tool had foreseen high values of heat transfer through windows and irradiation also through windows.

Considering that the building was built in the early 1980s, a time when Brazil still had no concerns about the energy efficiency of buildings, the result is not surprising. In the meantime, a proposal for the optimization of the house is presented.

The first of these is the replacement of the windows by more efficient models that correspond with the climatic needs of the place. In addition, passive ventilation and surround shading techniques in the building can collaborate to make it more efficient.

An even more ambitious proposal is to add solar panels to the roof of the building. Because it is not located in historical centre or areas that have strict rules regarding the aesthetics of the building, the application of the panels could help the building to achieve nearly zero needs, a concept still little explored, and innovative in this country.

5.4 Summary

The case studies showed that all the buildings analyzed are not energy efficient, probably considering their ages, dating from a time when this kind of concern was not yet taken into consideration when constructing a building. For this reason, the buildings are eligible to go through a rehabilitation process, to make the buildings not only energy efficient, but also to adapt them to the comfort criteria required nowadays.

The influence of the climate zone on the buildings under study is also noted. In Austria, a country located in a temperate zone with a predominantly cold climate, there is great concern about buildings' heating. In Brazil, on the contrary, heating is disregarded, and the predominant concern is with the cooling aspect of the building. Finally, Portugal is a country where both issues are important, mainly because it has cold winters and hot summers.

The analysis of the cases also shows how the choice of materials and building elements are extremely relevant. Windows, for example, have a great influence on heat transmission, and can have a great impact on a building. Using the right windows for the project, of good quality and installed correctly, could make a building energy efficient.

It is also important to emphasize the importance of passive solutions, such as surrounding shading or passive ventilation. These techniques can be a big advantage when it comes to the energy efficiency of a building.

Chapter 6

Comparative Analysis of Legislation and Energy Certificates

6. COMPARATIVE ANALYSIS OF LEGISLATION AND ENERGY CERTIFICATES

6.1 Overview

In general, it is noted that the regulations of Austria and Portugal have great similarities, since both have the European Union directives 2012/27/EU on energy efficiency and 2010/31/EU on the Energy Performance of Building as basis for the legislation of all member countries. Brazil, on the other hand, is committed to a different approach, both in the regulation and in the application of energy certification to residential buildings.

It is also possible to note that European countries already have energy efficiency policies in buildings longer than in Brazil. While Austria and Portugal already have target plans that determine the efficiency of their entire building stock, Brazil, although it reinforces the importance of these policies, still shows itself well behind Europe in this context.

In the following topic a comparative analysis of the legislation and energy certificates in the 3 countries will be made, in order to highlight the main differences between them and identify possible improvements, if necessary.

It is relevant to note that legislation and certificates can often be connected, as the energy ratings issued by these certificates are frequently pre-defined based on values referenced in national laws and regulations.

6.2 Comparative Analysis

For a comparative analysis, important characteristics were raised in determining the level of energy efficiency within residential buildings with a focus on rehabilitation.

As mentioned in the previous topic, the similarities between the Austrian and Portuguese legislation and certification are notorious. Not only because they follow the guidelines proposed by the European Union, but also because of the climate. Although at different levels, both have a temperate climate, while Brazil has in its majority a tropical climate.

The results presented in Table 24 will be analysed in order to highlight the differences, qualities, and possible flaws that each program may present. The analysis also foresees the reasons why such programs were designed in this particular way.

In addition, considering the application to the case studies, the positive and negative points of each one will be highlighted, besides emphasizing how the programs have influenced in the search for optimizing the projects in order to make the buildings in matter more energy efficient.

Table 24- Comparative Analysis between legislation and energy certifications.

	Characteristics	**Austria**	**Portugal**	**Brazil**
Legislation	Definition of the NZEB concept.	yes	yes	no
	Application of the NZEB concept.	yes	yes	no
	Differentiation between new buildings and buildings to be rehabilitated.	yes	yes	no
	Differentiation between housing buildings and service buildings.	yes	yes	yes
	Calculation of the CO2 emission	yes	yes	no
	Calculation of the heating demand	yes	yes	yes
	Calculation of the cooling demand Hot water energy demand Solar gains	yes	yes	yes
	Calculation of the primary energy demand	yes	yes	yes
	Division of the country in different bio-climatic zones	no	yes	yes
	It has its own certificate.	yes	yes	yes
	Reference values.	yes	yes	no
	Determination of energy efficiency.	yes	yes	no
	States or provinces are free to set their own standards.	yes	no	no
Energy Cetification	Analysis of the thermal quality of the building envelope.	yes	yes	yes
	Age of the building.	no	yes	no
	Presents different criteria for new buildings and buildings to be rehabilitated.	yes	yes	no
	Efficiency rating ranges	9	8	5
	Definition of reference values for thermal transmittance coefficients of building elements.	yes	yes	yes
	Definition of reference values for thermal capacity of building elements.	no	no	yes
	Definition of reference values for solar absorption of building elements.	no	no	yes

The first and second characteristics referred to, concern the determination and application of the NZEB concept in the legislation of each country. Both Austria and Portugal present not only the definition, but also reference values, target plans and financial incentives in order to make their housing stock with nearly zero energy requirements. Portugal, however, is more focused on not only creating new buildings with zero energy needs, but also rehabilitating the old ones in order to maintain their aesthetic and architectural characteristics, as well as their historical value, but still trying to achieve, if possible, the NZEB requirements.

Brazil, on the other hand, is behind the European countries in this respect. Although, in some isolated cases the NZEB concept is already implemented, the country's legislation does not present any demands in this respect. The legislation, however, encourages energy efficiency in general throughout the country, which resulted in the creation of the national energy efficiency plan, and consequently the creation of “Procel Edifica” certification.

Another relevant characteristic in the scope of the analysed legislations concerns the differentiation of requirements for new buildings and existing buildings to be rehabilitated. In Austria and Portugal this differentiation exists, while in Brazil does not. One of the reasons that European countries present this differentiation, has to do with the fact that these countries are older, and consequently the buildings are older too, with architectural, historical or aesthetic value. Brazil, on the other hand, presents a more recent building stock, with more modern construction elements, and with little patrimonial value. Thus, the concept of rehabilitation does not have so much strength in this country.

One issue that is considered in the 3 countries is the differentiation between housing buildings and public or service buildings. This distinction is necessary, mainly, in the issue of comfort needs. Thus, issues such as heating, and cooling needs have different approaches according to the functionality of the building.

The determination of the primary energy demand, heating demand and cooling demand is considered in all countries analysed in this study. It may come as a surprise to consider the heating load for a tropical country; however, southern Brazil has a temperate climate similar to the European one, which justifies this calculation. In the case study, however, this demand was not considered, because the bioclimatic zone in which the building is located does not present heating needs. Austria and Portugal, on the other hand, have cold winters, which justifies the importance of the heating demand in the calculation of the energy efficiency of the building.

In Austria, although the cooling has a regulation proposed by the OIB, the determining factor to be considered is not so relevant for the case study. The house used in this work, is located in a cold region and is mostly used as a tourist house in the cold winters of the Austrian mountains. The positive point of presenting a regulation for cooling demand even when the climate is mostly cold, is that in summer, the buildings have the ability to be comfortable for their users even on the hottest days.

In Brazil, on the other hand, due to its climate that presents hot days throughout the year, only the cooling needs were calculated. However, in practice, it is known that residential buildings do not have this concern when they are constructed. The most common technique used in the country is multi-split air conditioning systems, which is only added at the end of the construction, if the owner is able to afford this system. The low-income family homes do not have any cooling system. The most common in these cases is the acquisition of small portable fans that serves only one room at a time. A good proposal to improve the efficiency of these buildings, would be the application of passive techniques of natural ventilation in the construction elements of the building, thus reducing the need for the use of fans and air conditioning.

In relation to CO2 emissions, Brazil does not use this variable as a determining factor for policies related to the construction or rehabilitation of buildings. In times when sustainability and ecological concerns are increasingly important, it would be advisable for the Brazilian government to update its regulations in order to include this factor in the scope of civil construction.

As expected, primary energy demand is essential for determining the energy efficiency of buildings in all countries. However, the reference values are different, since each country is located in a different climate zone, which influences the reference value.

Both Portugal and Brazil consider different bioclimatic zones in the country. As mentioned above, the climate has great influence on the energy efficiency of a building. Brazil is a country of continental magnitude, and as a consequence it has numerous microclimates. Its legislation divides the country into 8 zones, which influences the coherence of the calculations performed. In the case study presented, the building is located in zone 6, in the centre-west of Brazil. Portugal, although in smaller scales, is divided into 3 winter and 3 summer climatic zones.

In opposition Austria is not divide into different bioclimatic zones. However, unlike Brazil and Portugal, the country allows states/provinces to adjust their standards to what they consider most coherent for the reality of their climates. This flexibility allows local regulations to positively influence building efficiency, just as the division of bioclimatic zones influences building laws in the other countries mentioned in this study.

One of the most important points of this analysis is the obligation to follow the energy efficiency regulations for residential buildings. It is understood that the members of the European Union are not only obliged to follow the planned benchmarks, but also present dates for the target plans to be met. In the case of NZEB buildings, Austria and Portugal need to make their housing stock meet these requirements. In the case of new public buildings, it has been implemented since 1st of January of 2019 and private. This will be mandatory for new private buildings after 31st of December 2020. While in the case of buildings to be rehabilitated, even though the NZEB standards are more up-to-date, they still need to be effectively followed since it is not officially implemented yet.

On the other hand, in Brazil, even if there are programs that present reference values for the execution of an energy-efficient building project, the law still does not establish an obligation for them to be followed. The law of energy efficiency in Brazil, works for the encouragement of actions in general, which resulted in the creation of several certification programs, however, there is no plan of targets that buildings are required to follow, nor dates provided for an obligation to do so.

Due to its magnitude and significant population, Brazil should create stricter laws regarding the obligatory execution of energy-efficient techniques, in general, and especially in the field of civil construction. In terms of sustainability, the country has great influence on environmental changes, which makes it even more important to make the population aware of the relevance of this issue.

The comparative analysis also points out that all legislation has created a form of energy certification, either directly by the regulations provided by law, or by the creation of complementary plans and programs, such as Procel Edifica.

Already in the scope of energy certification, some characteristics have proved to be very relevant for the building to obtain the maximum classification. A very important criterion that is addressed in all the certifications analysed is the thermal quality of the building envelope. Its importance is unquestionable, since it is in the envelope where the biggest heat transmissions occurs, either through the walls, the windows or the roof. The loss (or gain) of heat represents high levels of energy demand for both heating and cooling, resulting in a high energy demand value.

(or, Only in the Portuguese certification the values of the criteria are related with the age of (year of construction) the buildings. As mentioned above, this country is very concerned with existing buildings, especially those that have historical value, or that are located in places where the original aesthetics of the building generates patrimonial value to the property. Thus, Portugal has numerous building rehabilitation policies, such as regulations. Perhaps for this reason, the age of the building is such a relevant factor in rehabilitation projects that aim to apply the REH reference values.

Still related to the topic of building rehabilitation, both Austria and Portugal present differences in their energy certification systems for new and existing buildings (to be rehabilitated). One possible explanation is the fact that both countries are quite old, and thus have a housing stock that does not follow the comfort levels required nowadays. Brazil, a more recent country, presents an almost insignificant amount of buildings with historical value, in such a manner that makes the rehabilitation an activity very little explored.

Perhaps one of the differences that stands out most is the range of classifications that each one of the certifications presents. Austria has 9 ranges, ranging from G (most inefficient level) to A++ (most efficient level), based on the values of maximum heat demand, maximum final energy demand, maximum primary energy demand and total energy efficiency factor. Portugal has 8 levels, from F to A+, which are represented by the values of the ratio between the primary needs' indicator of the building and the primary needs indicator of the reference building. Finally, Brazil presents a scale of 5 classifications, from E to A. This certificate presents efficiency levels according to scores obtained considering the calculation of the numerical equivalent of the envelope and the numerical equivalent of the water heating system, when applicable. In addition, the coefficient related to the bioclimatic zone of the place where the building is located, and some possible bonuses are also used.

Finally, it is analysed if the certificates present a predetermination of the thermal transmittance values of the building elements, as well as the thermal capacity and solar absorption values. Only the Brazilian certificate presents specific values for such coefficients, while Austria and Portugal pre-establish only the U-values. In addition, Portugal also establishes the solar factor during summer.

When applied to case studies of buildings to be rehabilitated these three countries, it is noticeable that, in general, the Austrian certificate presents simpler calculations as well as a succinct explanation of what is established. The Portuguese certificate, on the other hand, has great similarities to the Austrian certificate, but with a slightly greater complexity in the calculations, although still well accessible to professionals in the area. Finally, the Brazilian certificate proved to be very complex, with countless variables and coefficients. One possible reason for this is that it is not mandatory to obtain such certification. Once the law provides for its obligation, it is expected that the language used by the certificate will be simpler, in order to facilitate its application in the scope of civil construction.

Chapter 7

Conclusions and Future Work

7. CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

After the comparative analysis between legislation and energy certifications, it can be noted that some characteristics have extreme relevance for calculating the energy efficiency of a building.

After the application of legislation and certification to the case studies, the first characteristic to be highlighted is the climate zone in which the building is located. The outdoor climate has a great influence on the building envelope not only in relation to heat and cold, but also in matters such as ventilation and humidity.

It is notorious that due to the climate, both European countries have great concerns about the heating of the building, because the winter months require that the thermal comfort of users should be maintained inside the building, even with extremely low temperatures outside. In Brazil, a tropical country, there is no such concern in this sense, since a large part of the country does not have extremely cold winters. However, its regulation presents reference values for cases where buildings need to be heated, usually in the south of the country.

Because of such importance, the quality of the building envelope was addressed several times throughout this study. The thermal transmittance value showed its relevance by being a determining factor for classifying the energy efficiency of the building. Thus, knowing the U-values of the walls, windows, roof and floor in contact with the ground, it was possible to calculate the current level of efficiency of buildings. Not only that, with these values it was possible to identify the elements that had more heat transmission, therefore, the elements that need to be changed in a rehabilitation for the building to become efficient.

Perhaps the most significant aspect to be highlighted is the perception that buildings have a major impact on the energy sector, and it is up to construction professionals to apply the techniques that enable buildings to become as efficient as possible, or even, in more ambitious plans, with nearly zero or no energy needs.

In recent decades, several countries, especially the members of the European Union, have already applied these techniques to new buildings, and in recent years they have also been applied to buildings under rehabilitation. On the other hand, it is noticeable that some countries still do not have the political, social and economic conditions to put these plans as a priority.

This is the case in Brazil, which even though it already has a regulation that establishes reference values that delimit high levels of efficiency for buildings, such values are not yet considered mandatory. The expectation, on the other hand, is positive, since the first steps in relation to energy efficiency have already been taken, only the effectiveness of the plans created is lacking.

The comparative analysis of legislation, in a way, proves what was stated above. European countries present in their laws target plans to be accomplished effectively, such as dates for all their building stock to be composed of NZEB buildings. Brazil, meanwhile, presents a very wide-ranging of energy efficiency laws, which does not impose any direct goal or limit to be achieved, especially in the field of civil construction.

As for energy certificates, the analysis showed that each country has different methods for energy efficiency calculations, as well as different intervals. However, they also showed great similarities, especially the two European countries. They all emphasize the importance of the thermal quality of the envelope for the building to become efficient, whether in cold or hot climates, which helped in the search for optimal solutions for the case studies in Kitzbühel, Vila Real and Goiânia.

7.2 Future Work

In future work, the comparative analyses of energy legislation and certifications should be extended to other countries with different climate zones, such as China or India. This comparison can show whether the criteria used to obtain certifications are the same in different nations.

Another future work that should be carried out soon is a comparison of the updated versions of laws and regulations that were presented in this study. In an optimistic view, Brazil will create stricter laws regarding the obligation of efficiency in its building stock.

The study of the existing policies and economic incentives, in the countries studied and other countries to encourage the owners rehabilitate their buildings, will be very useful.

To develop a software tool capable of dealing with different climate date, in order to make possible the comparison of the heating and cooling energy needs, in different countries.

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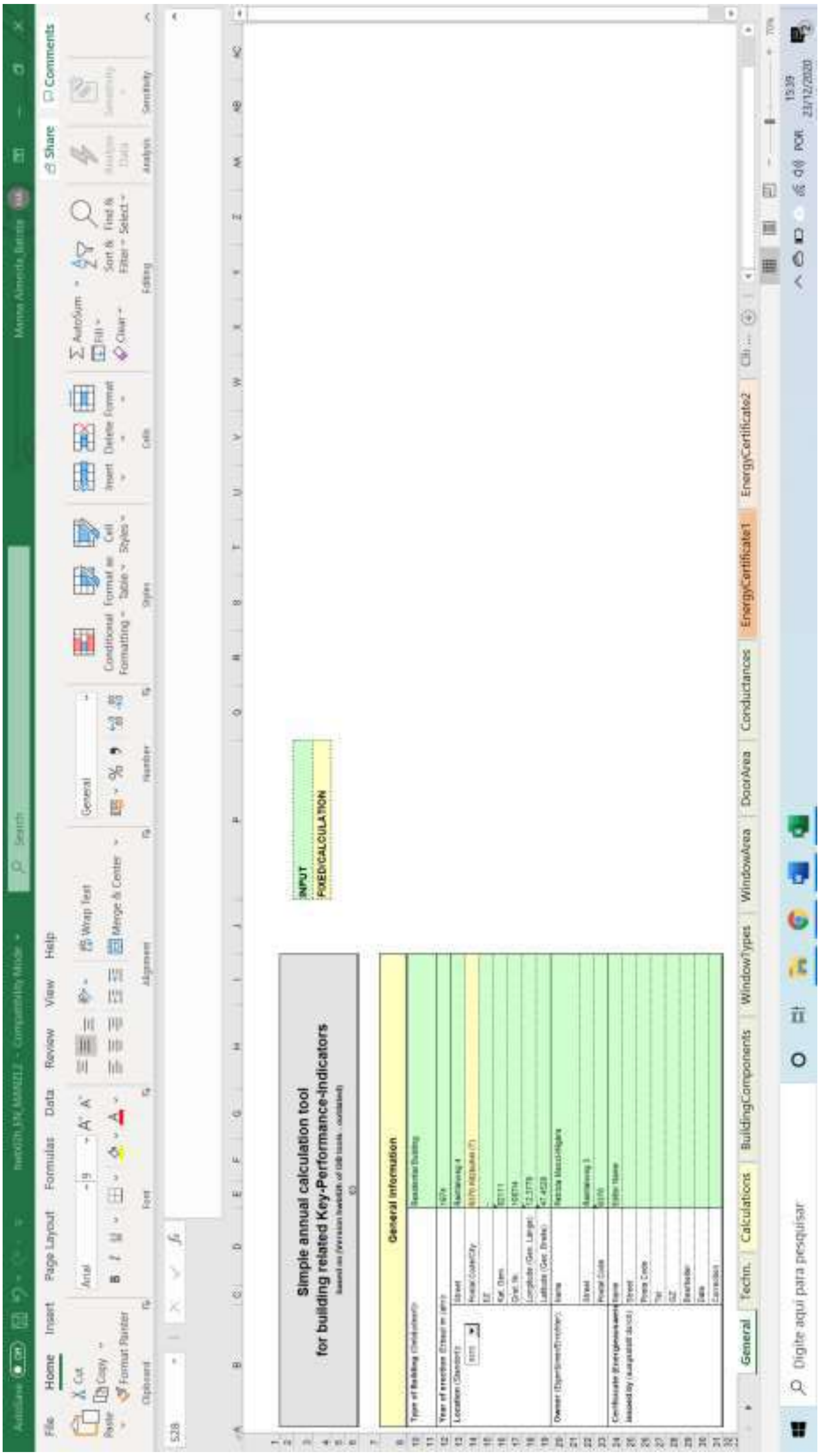
ANNEX 1 – HEATING CALCULATION - KITZBÜHEL

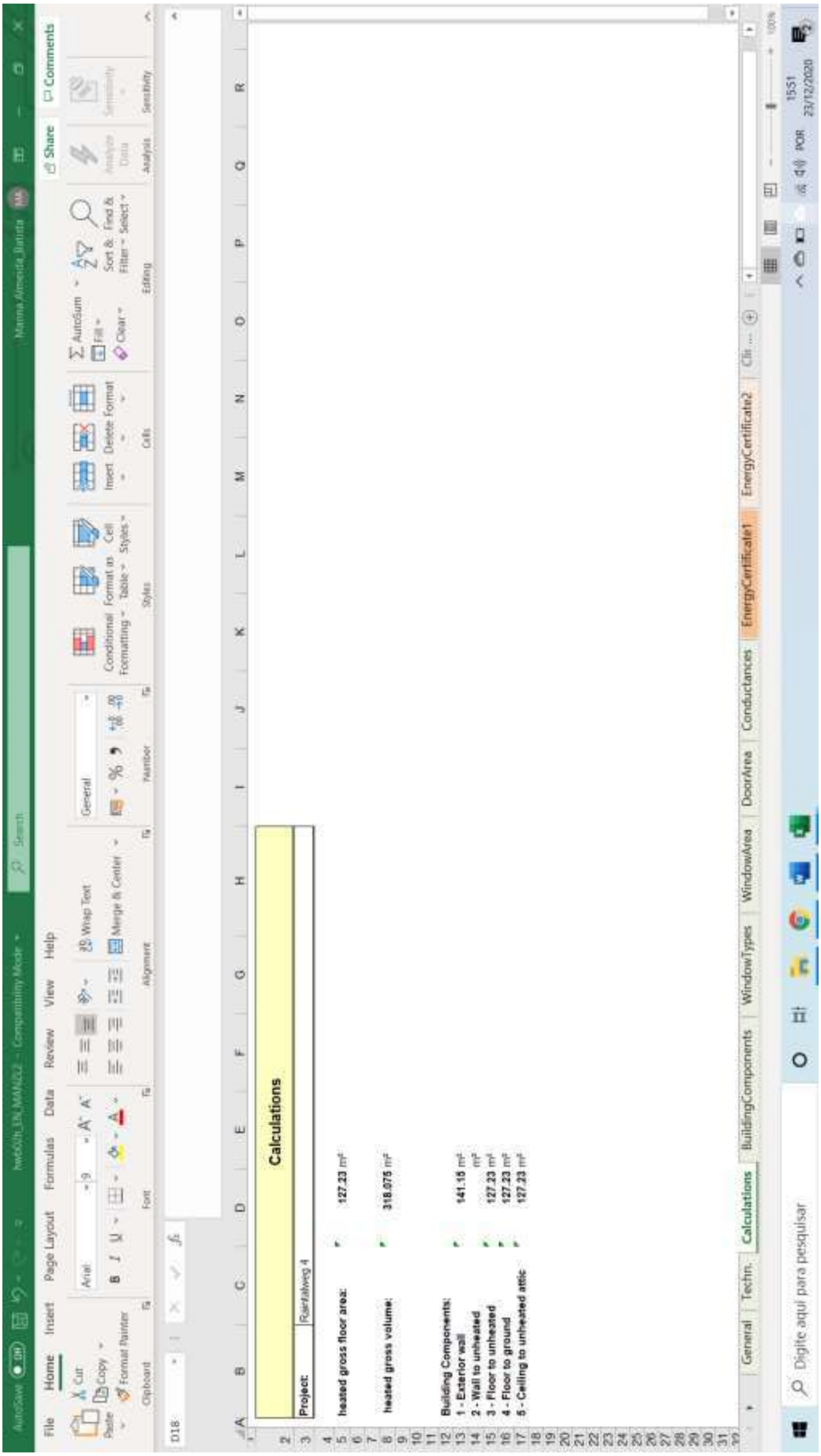


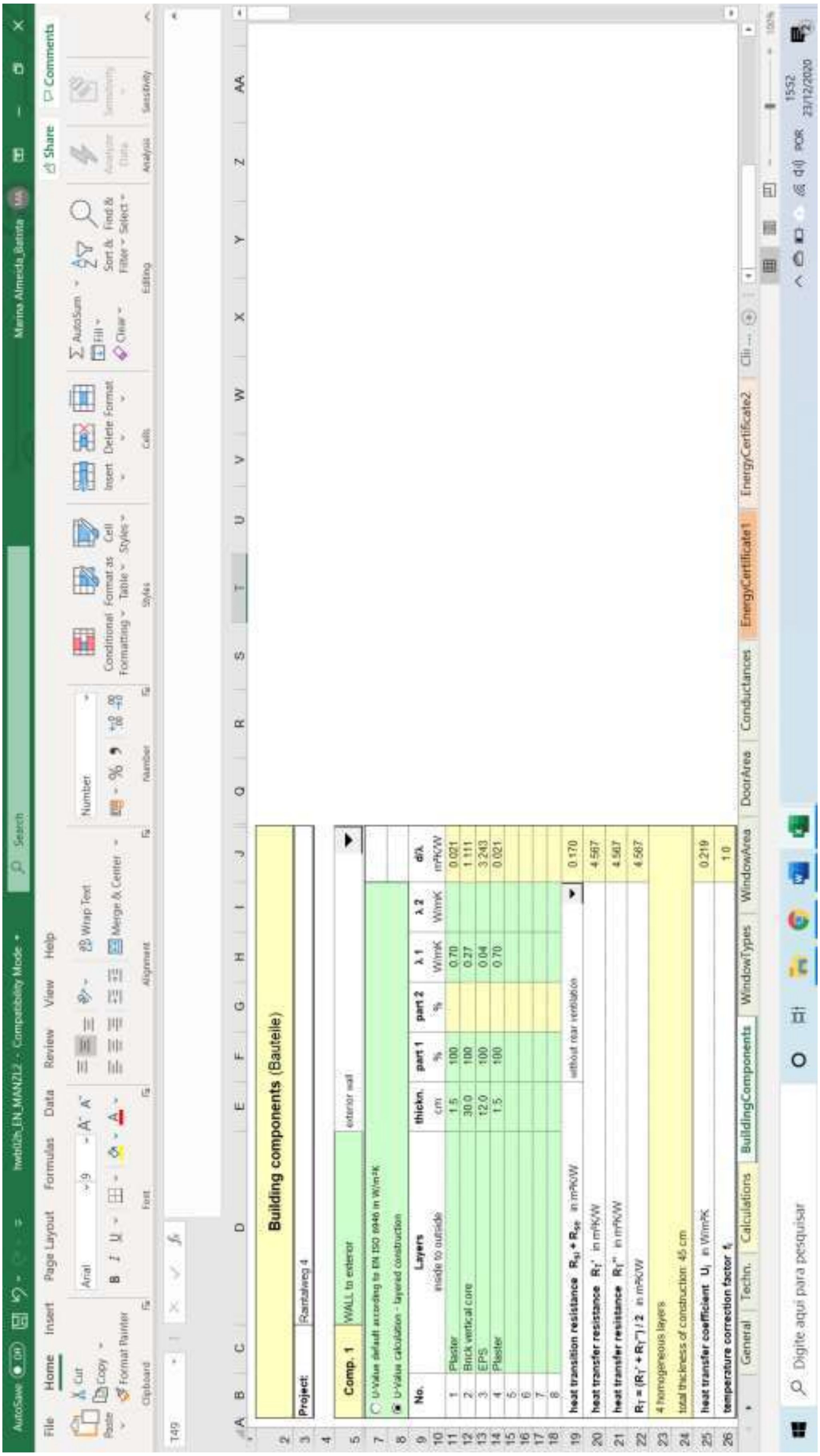
Technical specifications	
Project:	Raintalweg 4

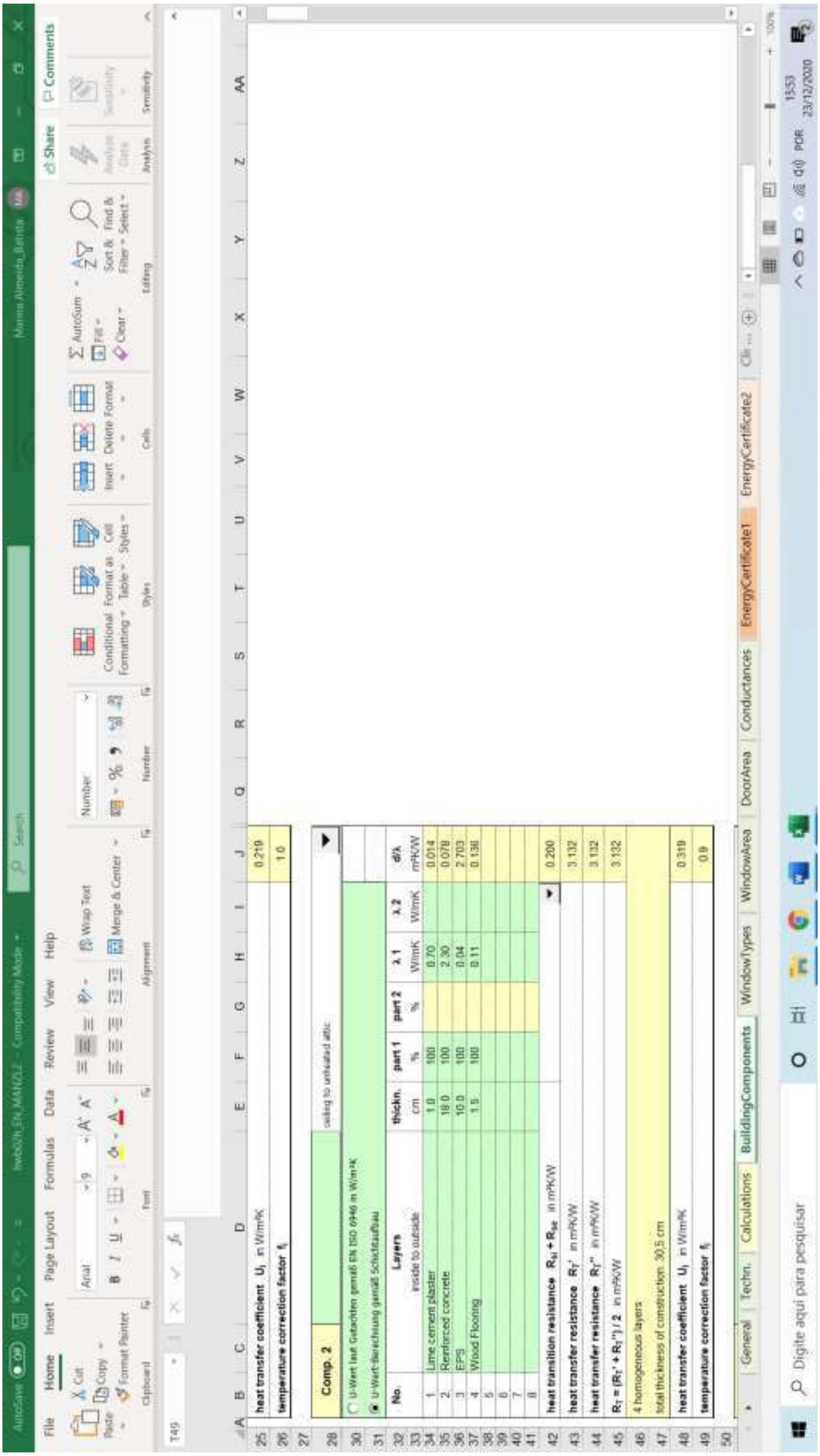
Building related information (Gebäude)		
Building-Usage	◯ Single family house	
	◉ Double family house	20 °C qi = 3,0 W/m²
	◯ Row/serial house	
	◯ Multi family houses	
	◯ Hospital	
	◯ Special-care home	
	◯ Office building	
	◯ School	
	◯ Other	
Building Construction Mass (Bauweise):	◯ heavy weight construction	
	◉ medium construction	ETA = 0,98
	◯ leight weight construction	

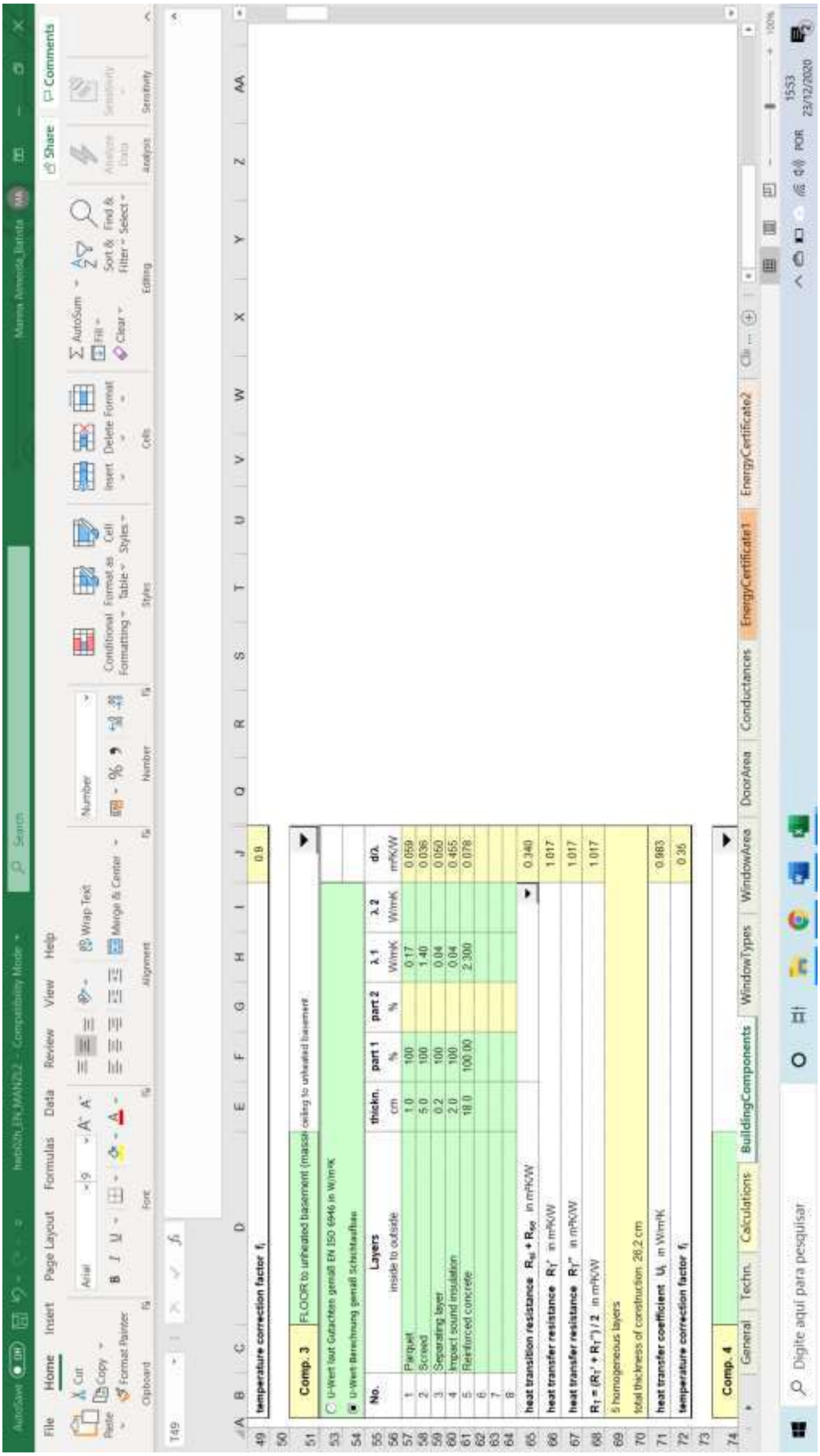
Principal perimeter (Abmessungen)	
heated gross Volume of building V_B in m³: (beheiztes Brutto-Volumen des Gebäudes)	**318.08**
heated gross area BGF_B in m²: (beheizte Brutto-Geschoßfläche)	**127.23**

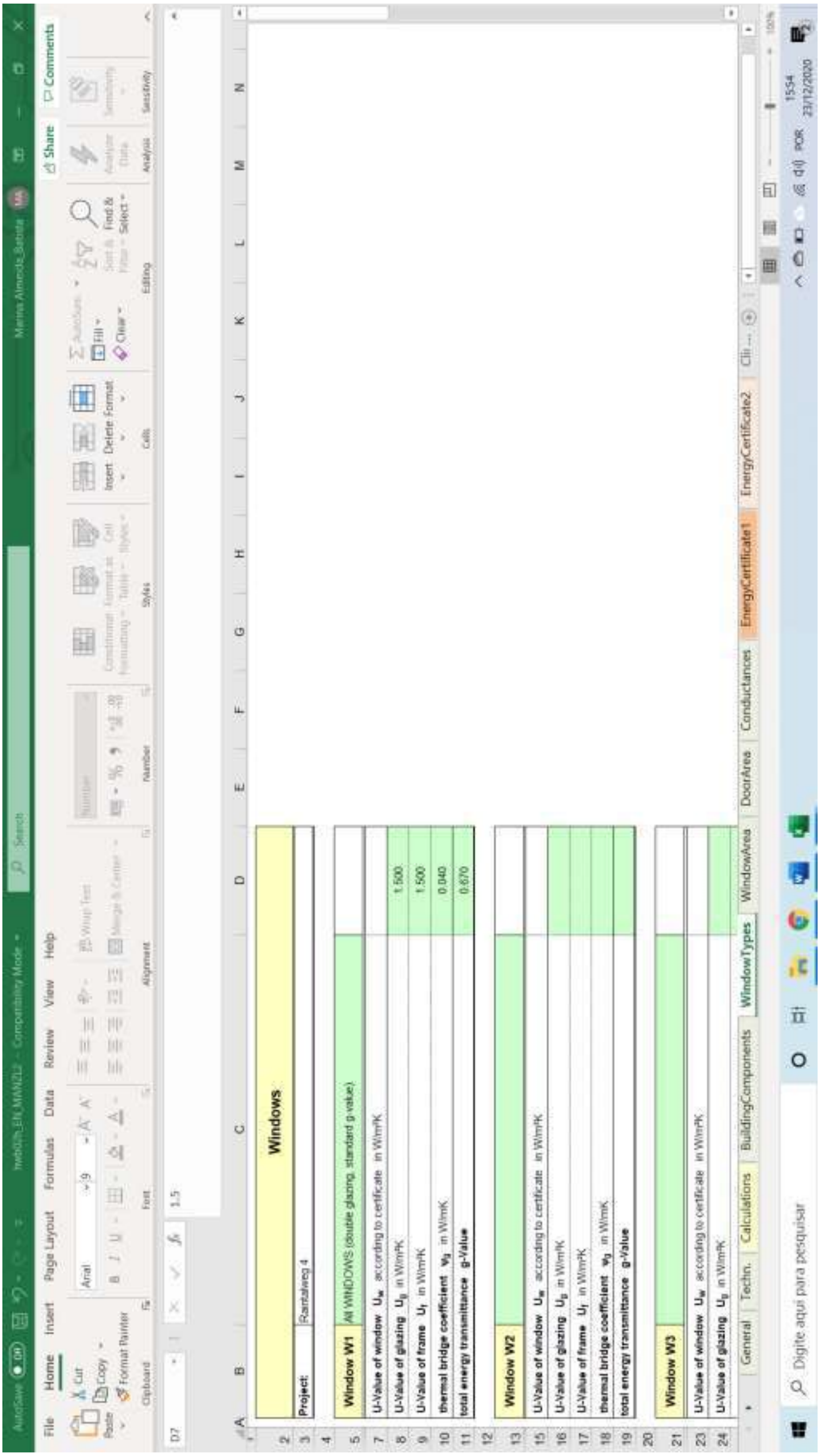
Transmission losses & Ventilation losses (Transmissions- und Lüftungswärmeverluste)		
Windows:	◯ U-Value - default	
	◉ U-Value - calculated	simple with: Ag = 0,7 * Aw and lg = 3 * Aw
Thermal-Bridges:	◉ Conductances added default (Leitwertzuschläge pauschal)	
	◯ according to: EN ISO 10211-1 in W/K	
Ventilation:	◉ Windows: air change rate in 1/h	0.40
	◯ mechanical ventilation	
	air change rate >= 0,4 in 1/h	
	heat recovery efficiency η_{WRG} in %	
	ground heat exchanger efficiency η_{EWT} in %	
	infiltration n_x in 1/h	
	total air change rate n in 1/h	0.40

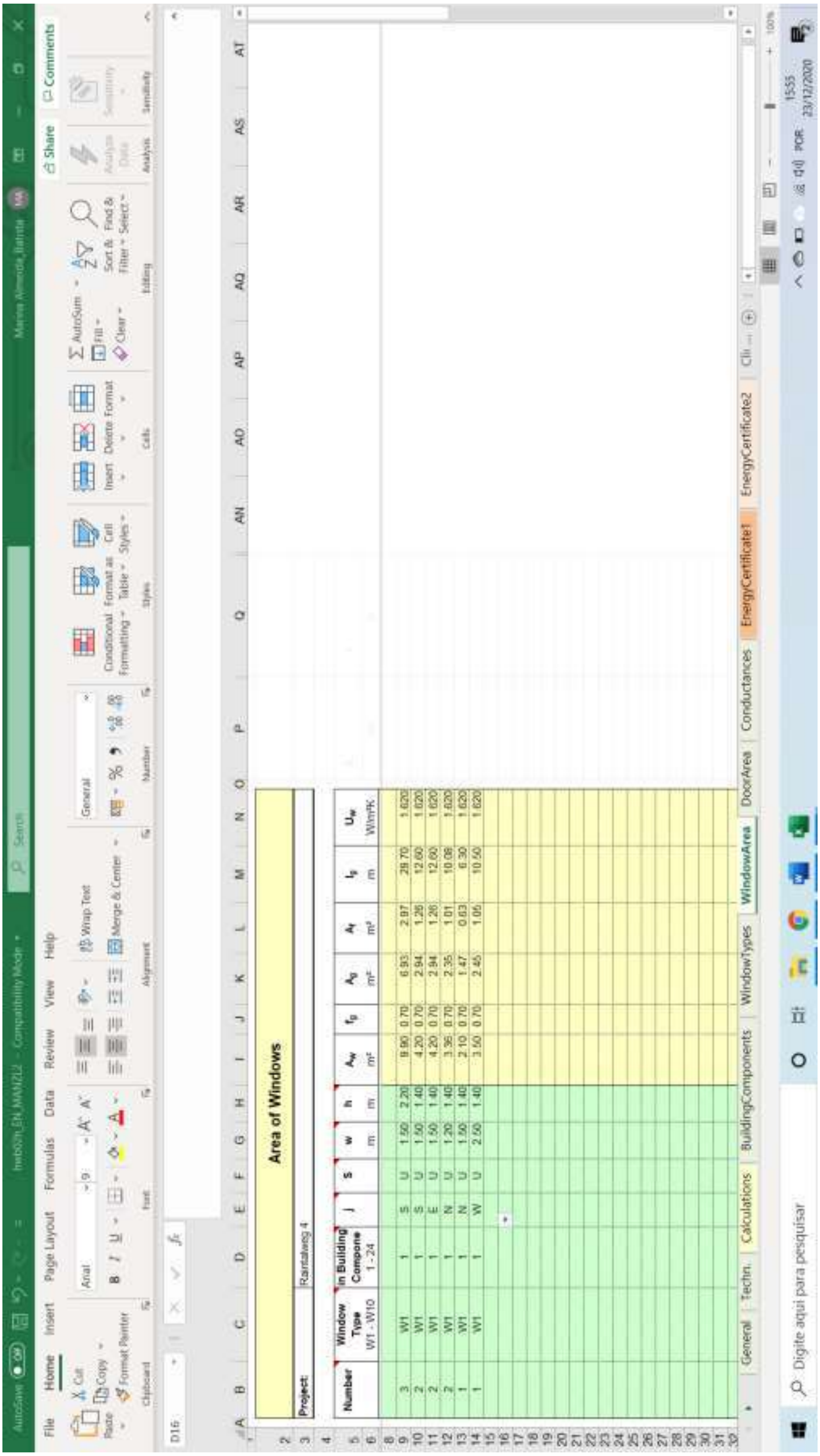

Calculations
Project:
heated gross floor area:
127.23 m²
heated gross volume:
318.075 m³
Building Components:
1 - Exterior wall
141.15 m²
2 - Wall to unheated
m²
3 - Floor to unheated
127.23 m²
4 - Floor to ground
127.23 m²
5 - Ceiling to unheated attic
127.23 m²
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2

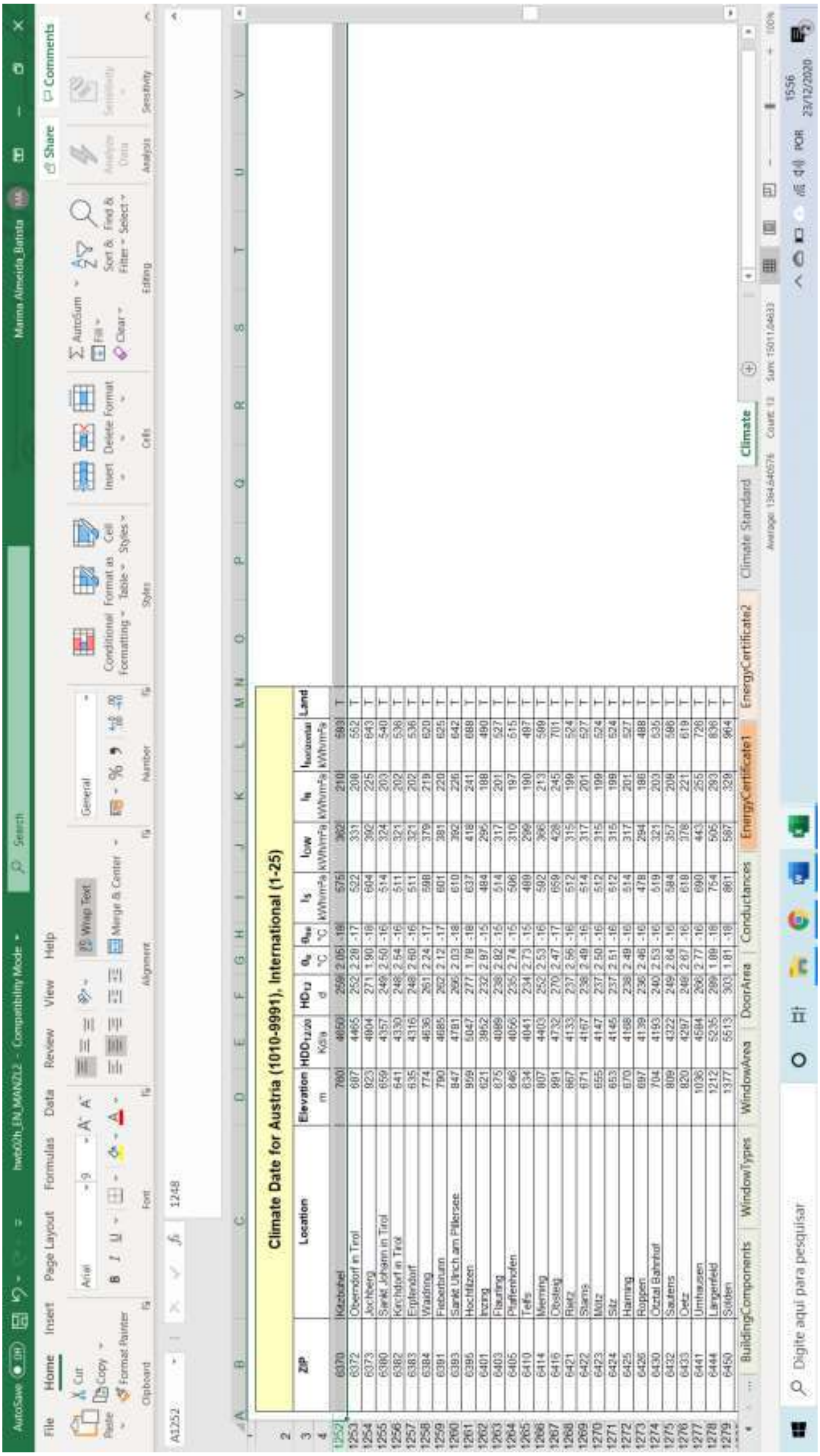

Building components (Bauteile)
Project:
Comp. 1
WALL to exterior
exterior wall
No.
Layers
inside to outside
thickn.
cm
part 1
%
part 2
%
λ 1
W/mK
λ 2
W/mK
d/λ
m²K/W
Plaster
Brick vertical core
EPS
Plaster
heat transition resistance
heat transfer resistance
heat transfer coefficient
temperature correction factor
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2


heat transfer coefficient U_i in W/m²K 0.219
temperature correction factor f_i 1.0
Comp. 2
ceiling to unheated attic
U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K
U-Wert-Berechnung gemäß Schichtaufbau
No. Layers inside to outside thickn. cm part 1 % part 2 % λ 1 W/mK λ 2 W/mK d/λ m²K/W
1 Lime cement plaster 1.0 100 0.70 0.014
2 Reinforced concrete 18.0 100 2.30 0.078
3 EPS 10.0 100 0.04 2.703
4 Wood Flooring 1.5 100 0.11 0.136
heat transition resistance R_si + R_se in m²K/W 0.200
heat transfer resistance R_T' in m²K/W 3.132
heat transfer resistance R_T'' in m²K/W 3.132
R_T = (R_T' + R_T'') / 2 in m²K/W 3.132
4 homogeneous layers
total thickness of construction: 30,5 cm
heat transfer coefficient U_i in W/m²K 0.319
temperature correction factor f_i 0.9


temperature correction factor
FLOOR to unheated basement
Parquet
Screed
Separating layer
Impact sound insulation
Reinforced concrete
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2


Windows
Project:
Window W1
All WINDOWS (double glazing, standard g-value)
U-Value of window
U-Value of glazing
U-Value of frame
thermal bridge coefficient
total energy transmittance g-Value
1.500
1.500
0.040
0.670
Window W2
Window W3
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2

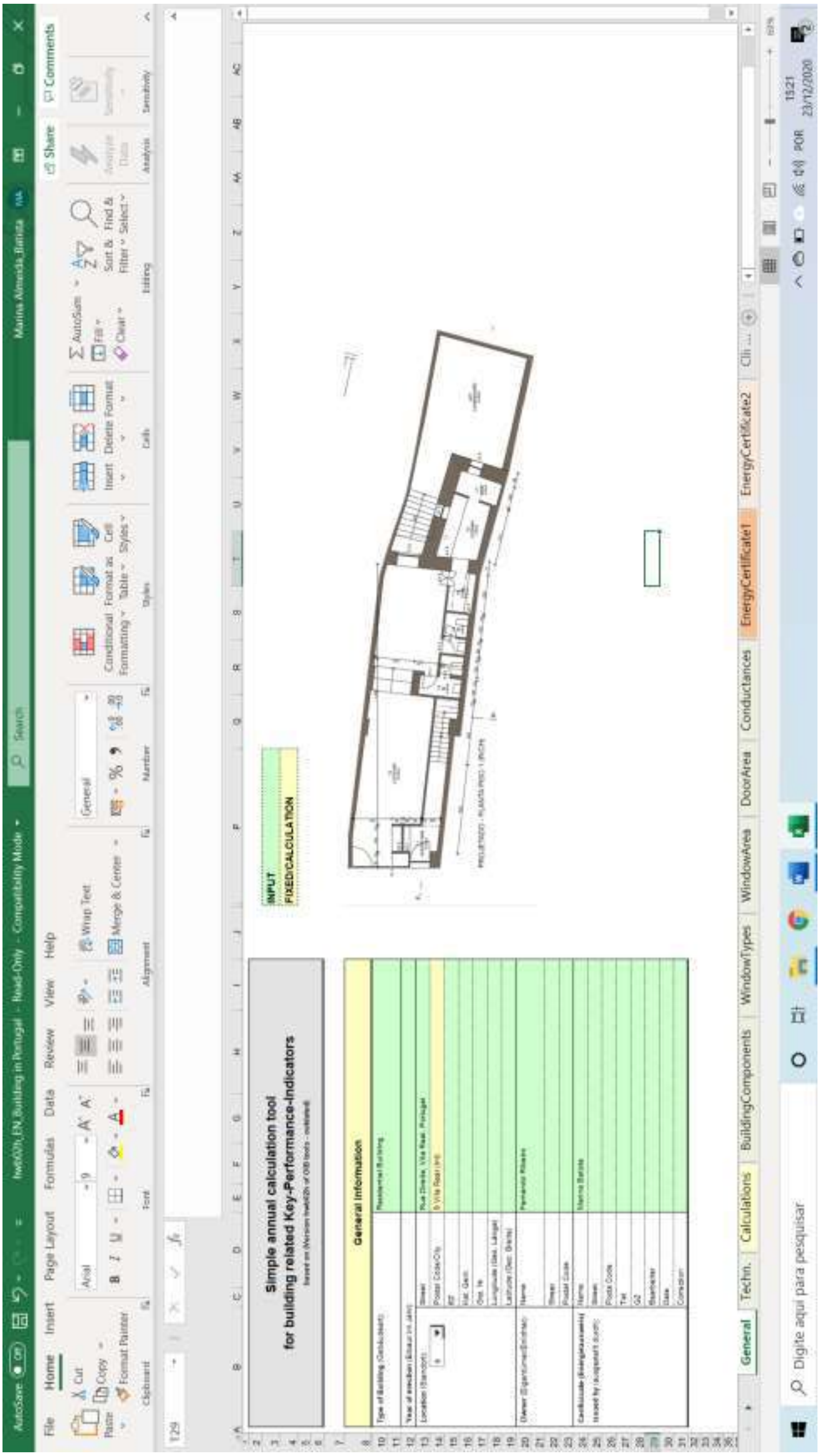

Area of Windows
Project:
Raintalweg 4
Number
Window Type W1 - W10
in Building Compone 1 - 24
J
S
w m
h m
Aw m²
fg
Ag m²
Af m²
lg m
Uw W/m²K
3 W1 1 S U 1.50 2.20 9.90 0.70 6.93 2.97 28.70 1.620
2 W1 1 S U 1.50 1.40 4.20 0.70 2.94 1.26 12.60 1.620
2 W1 1 E U 1.50 1.40 4.20 0.70 2.94 1.26 12.60 1.620
2 W1 1 N U 1.20 1.40 3.36 0.70 2.35 1.01 10.08 1.620
1 W1 1 N U 1.50 1.40 2.10 0.70 1.47 0.63 6.30 1.620
1 W1 1 W U 2.50 1.40 3.50 0.70 2.45 1.05 10.50 1.620
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2



Climate Date for Austria (1010-9991), International (1-25)

ZIP	Location	Elevation m	$HDD_{12/20}$ Kd/a	HD_{12} d	θ_e °C	θ_{ne} °C	I_S kWh/m²a	$I_{O/W}$ kWh/m²a	I_N kWh/m²a	$I_{horizontal}$ kWh/m²a	Land
6370	Kitzbühel	780	4650	259	2.05	-18	575	362	210	593	T
6372	Oberndorf in Tirol	687	4465	252	2.28	-17	522	331	208	552	T
6373	Jochberg	923	4804	271	1.90	-18	604	392	225	643	T
6380	Sankt Johann in Tirol	659	4357	249	2.50	-16	514	324	203	540	T
6382	Kirchdorf in Tirol	641	4330	248	2.54	-16	511	321	202	536	T
6383	Erpfendorf	635	4316	248	2.60	-16	511	321	202	536	T
6384	Waidring	774	4636	261	2.24	-17	598	379	219	620	T
6391	Fieberbrunn	790	4685	262	2.12	-17	601	381	220	625	T
6393	Sankt Ulrich am Pillersee	847	4781	266	2.03	-18	610	392	226	642	T
6395	Hochfilzen	959	5047	277	1.78	-18	637	418	241	688	T
6401	Inzing	621	3952	232	2.97	-15	484	295	188	490	T
6403	Flaurling	675	4089	238	2.82	-15	514	317	201	527	T
6405	Pfaffenhofen	646	4056	235	2.74	-15	506	310	197	515	T
6410	Telfs	634	4041	234	2.73	-15	489	299	190	497	T
6414	Mieming	807	4403	252	2.53	-16	592	366	213	599	T
6416	Obsteig	991	4732	270	2.47	-17	659	428	245	701	T
6421	Rietz	667	4133	237	2.56	-16	512	315	199	524	T
6422	Stams	671	4167	238	2.49	-16	514	317	201	527	T
6423	Mötz	655	4147	237	2.50	-16	512	315	199	524	T
6424	Silz	653	4145	237	2.51	-16	512	315	199	524	T
6425	Haiming	670	4168	238	2.49	-16	514	317	201	527	T
6426	Roppen	697	4139	236	2.46	-16	478	294	186	488	T
6430	Ötztal Bahnhof	704	4193	240	2.53	-16	519	321	203	535	T
6432	Sautens	809	4322	249	2.64	-16	584	357	208	586	T
6433	Oetz	820	4297	248	2.67	-16	618	378	221	619	T
6441	Umhausen	1036	4584	266	2.77	-16	690	443	255	726	T
6444	Längenfeld	1212	5235	289	1.89	-18	754	505	293	836	T
6450	Sölden	1377	5513	303	1.81	-18	861	587	329	964	T

ANNEX 2 – HEATING CALCULATION – VILA REAL



Technical specifications

Project:	Rua Direita, Vila Real, Portugal

Building related information (Gebäude)

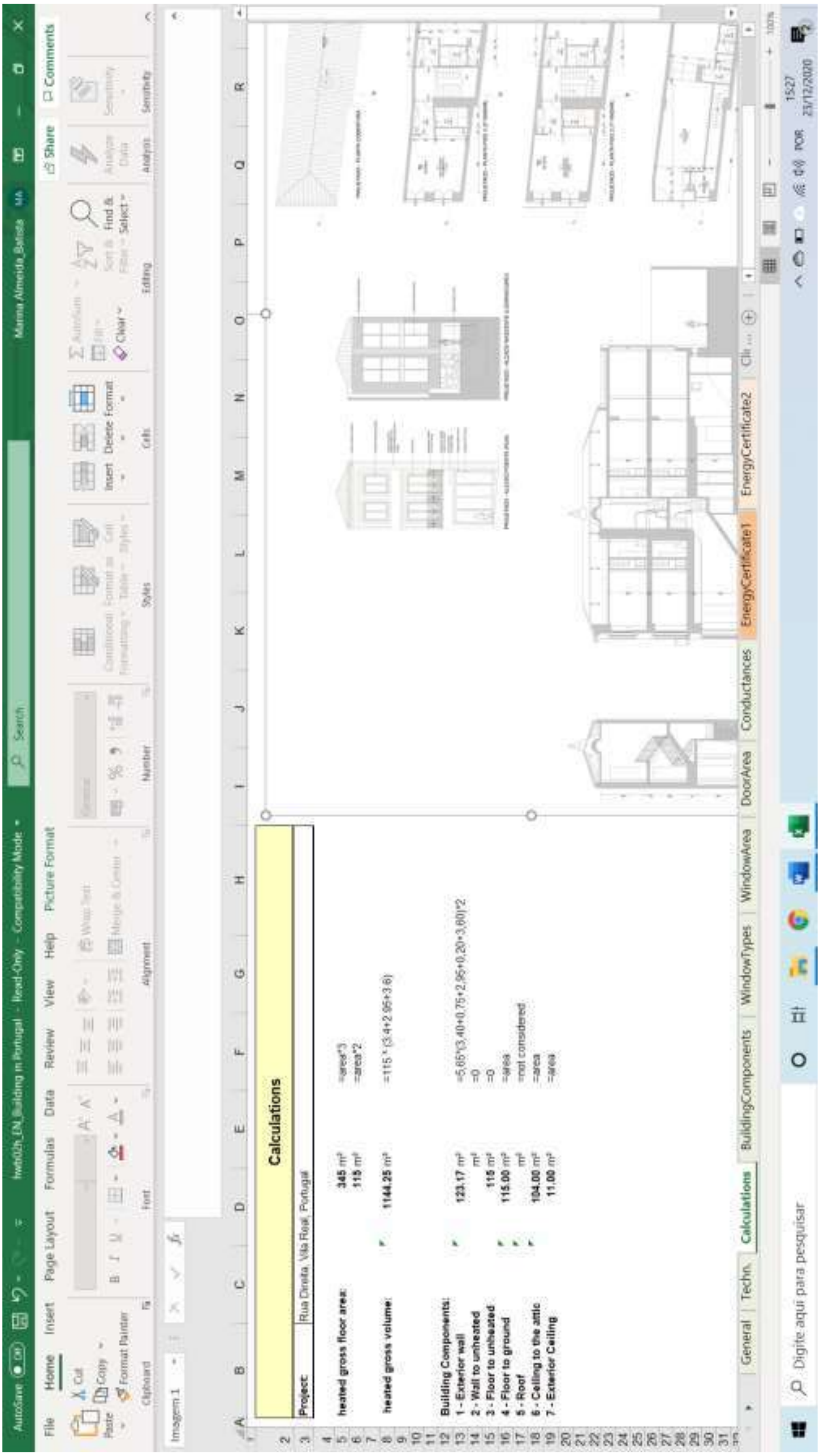
Building-Usage	(●) Single family house	20 °C qi = 3,0 W/m²
	( ) Double family house	
	( ) Row/serial house	
	( ) Multi family houses	
	( ) Hospital	
	( ) Special-care home	
	( ) Office building	
	( ) School	
	( ) Other	
Building Construction Mass (Bauweise):	( ) heavy weight construction	
	(●) medium construction	ETA = 0,98
	( ) leight weight construction	

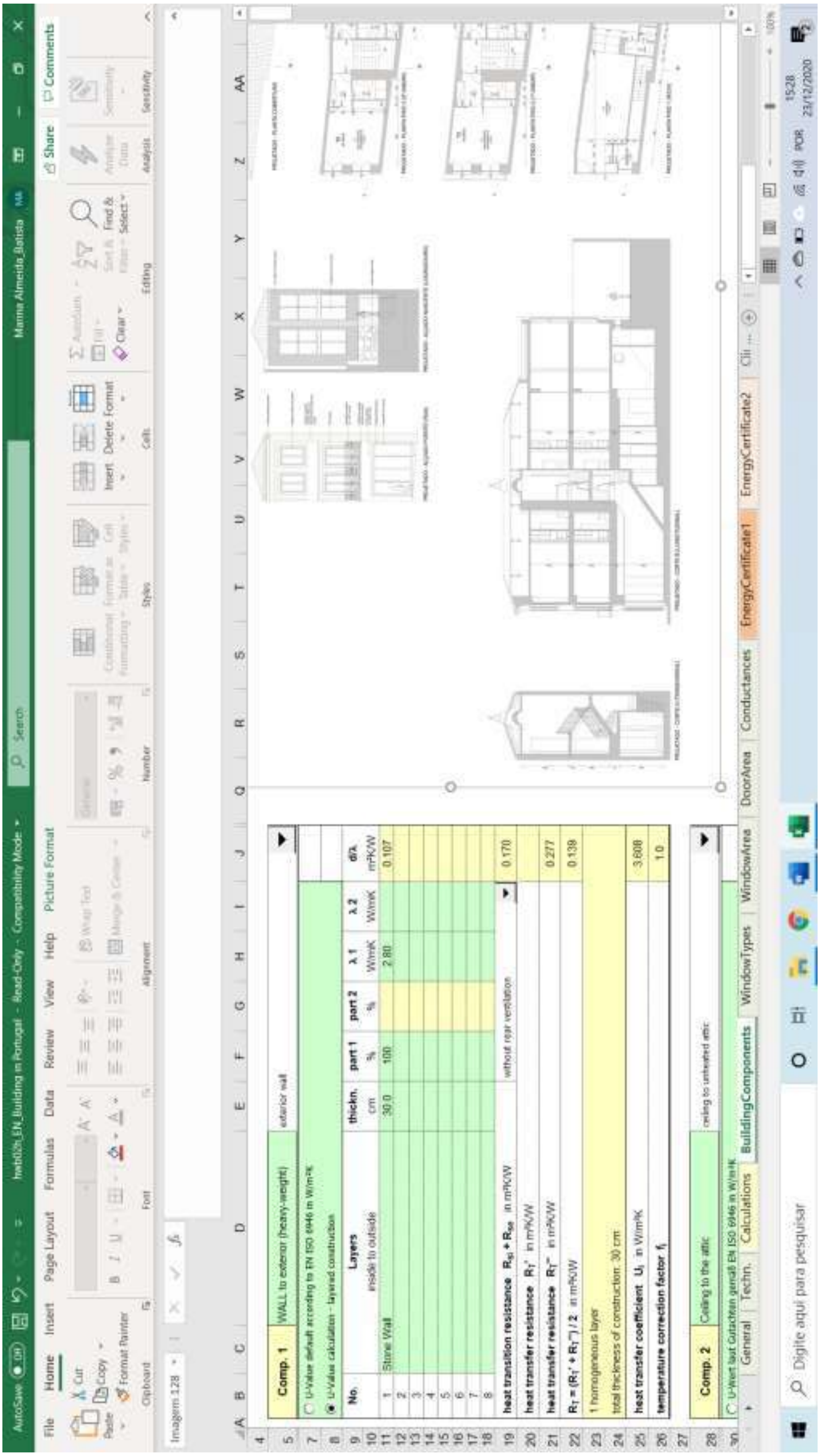
Principal perimeter (Abmessungen)

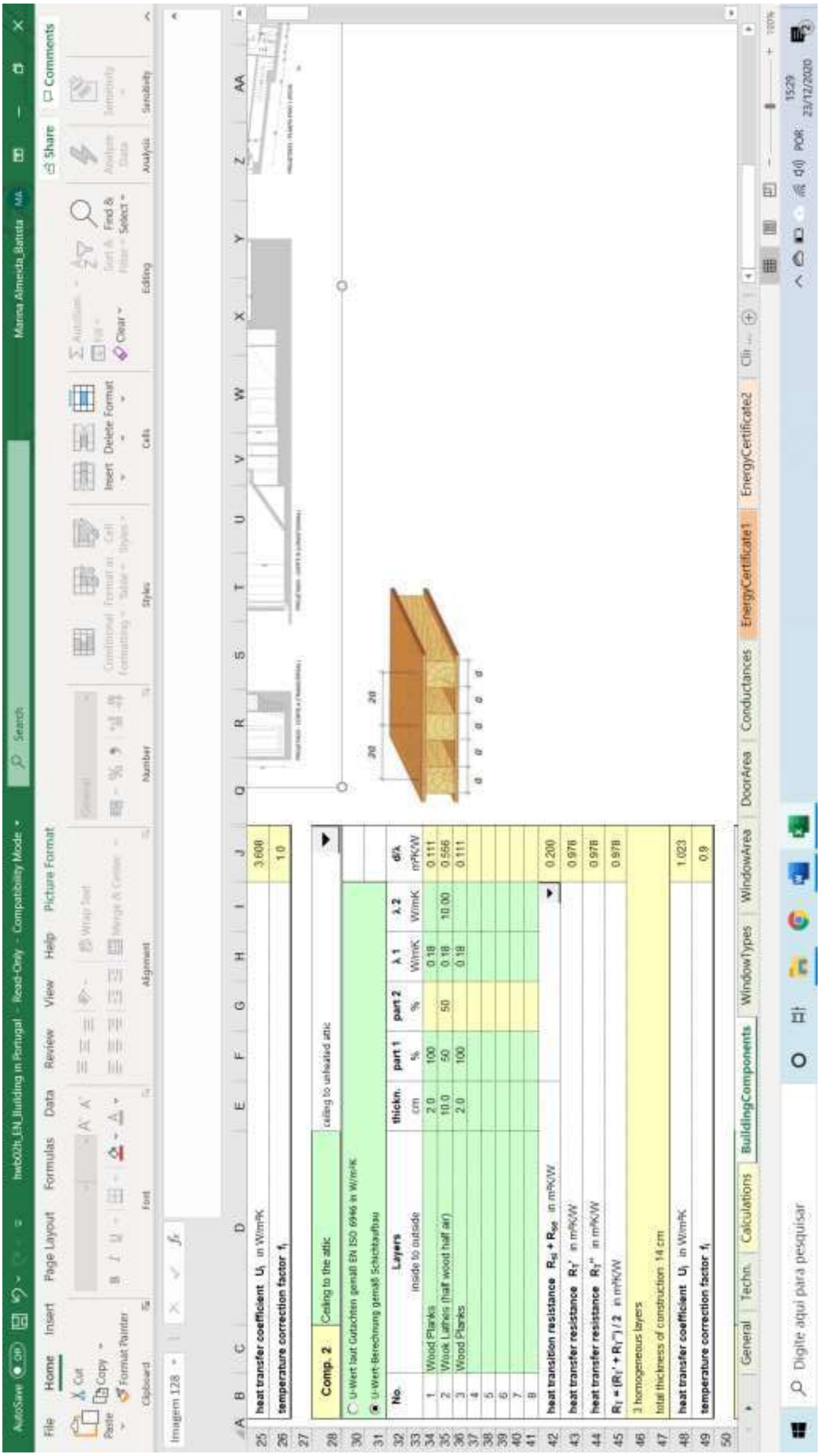
heated gross Volume of building V_B in m³: (beheiztes Brutto-Volumen des Gebäudes)	**1144.25**
heated gross area BGF_B in m²: (beheizte Brutto-Geschoßfläche)	**345.00**

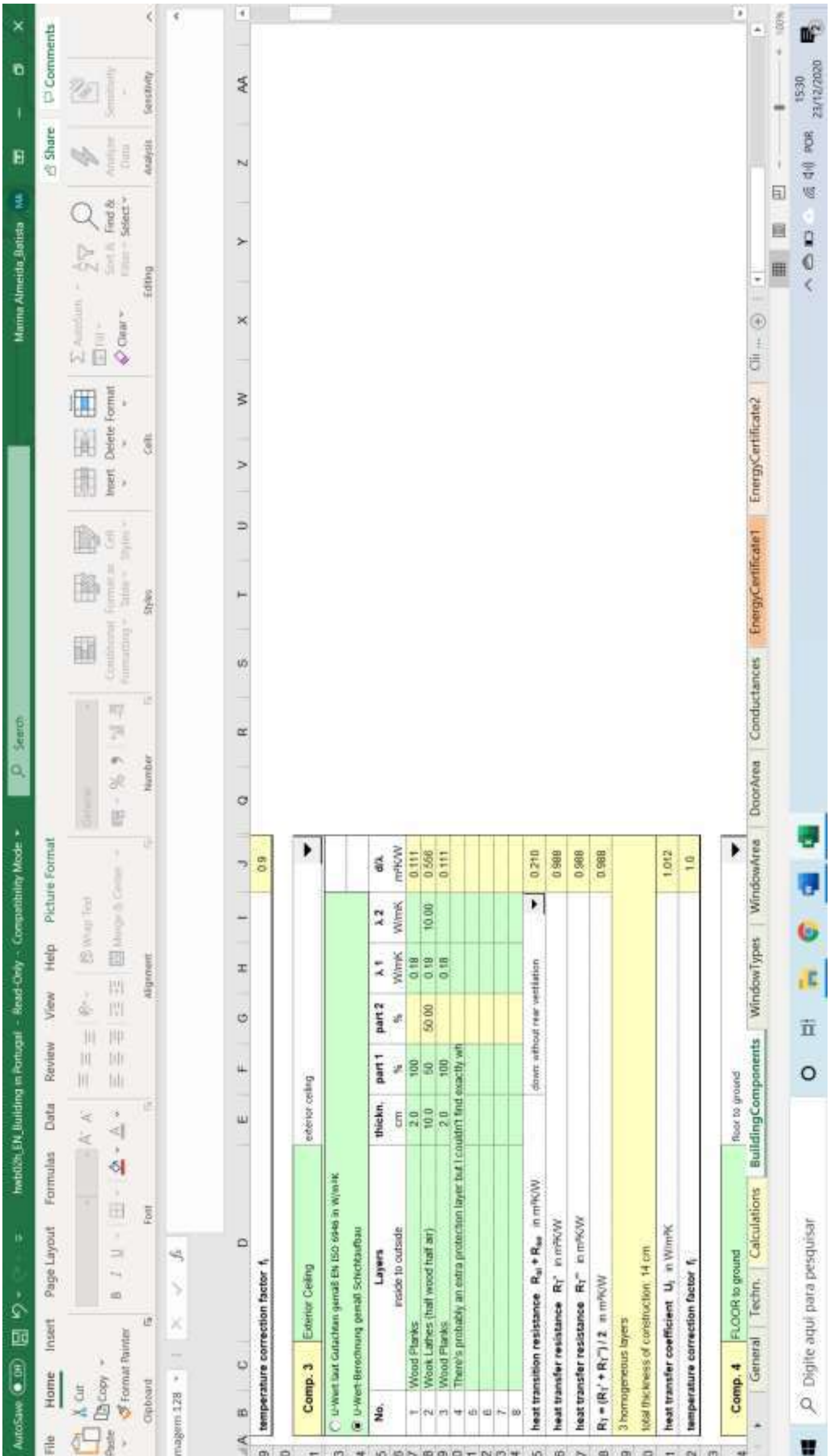
Transmission losses & Ventilation losses (Transmissions- und Lüftungswärmeverluste)

Windows:	( ) U-Value - default	
	(●) U-Value - calculated	simple with: Ag = 0,7 * Aw and lg = 3 * Aw
Thermal-Bridges:	(●) Conductances added default (Leitwertzuschläge pauschal)	
	( ) according to: EN ISO 10211-1 in W/K	
Ventilation:	(●) Windows: air change rate in 1/h	0.40
	( ) mechanical ventilation	
	air change rate >= 0,4 in 1/h	
	heat recovery efficiency η_{WRG} in %	
	ground heat exchanger efficiency η_{EWT} in %	
	infiltration n_x in 1/h	
	total air change rate n in 1/h	0.40

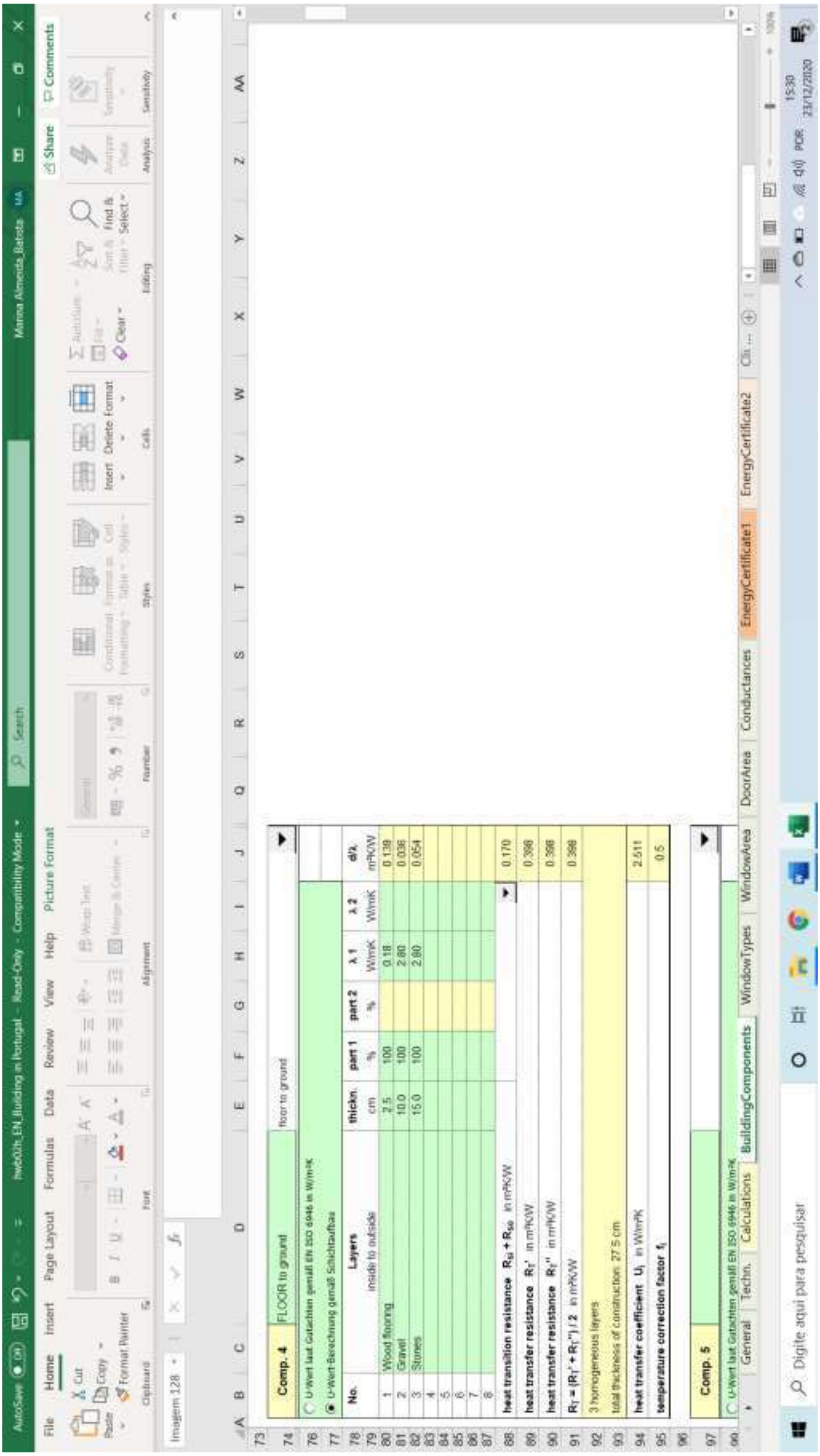

Calculations
Project:
Rua Direita, Vila Real, Portugal
heated gross floor area:
345 m²
115 m²
=area*3
=area*2
heated gross volume:
1144.25 m³
=115 * (3.4+2.95+3.6)
Building Components:
1 - Exterior wall
2 - Wall to unheated
3 - Floor to unheated
4 - Floor to ground
5 - Roof
6 - Ceiling to the attic
7 - Exterior Ceiling
123.17 m²
m²
115 m²
115.00 m²
m²
104.00 m²
11.00 m²
=0
=0
=area
=not considered
=area
=area
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2

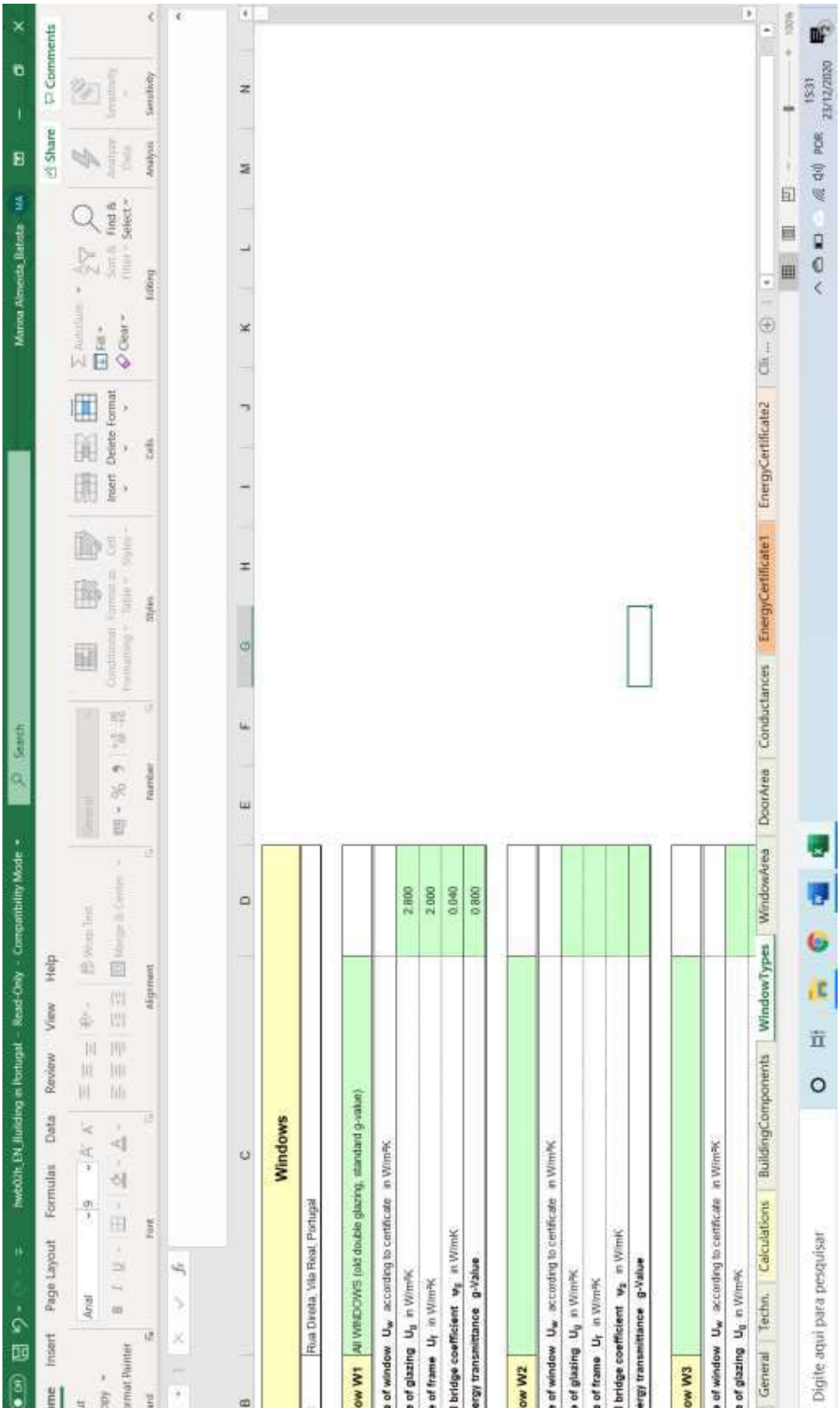


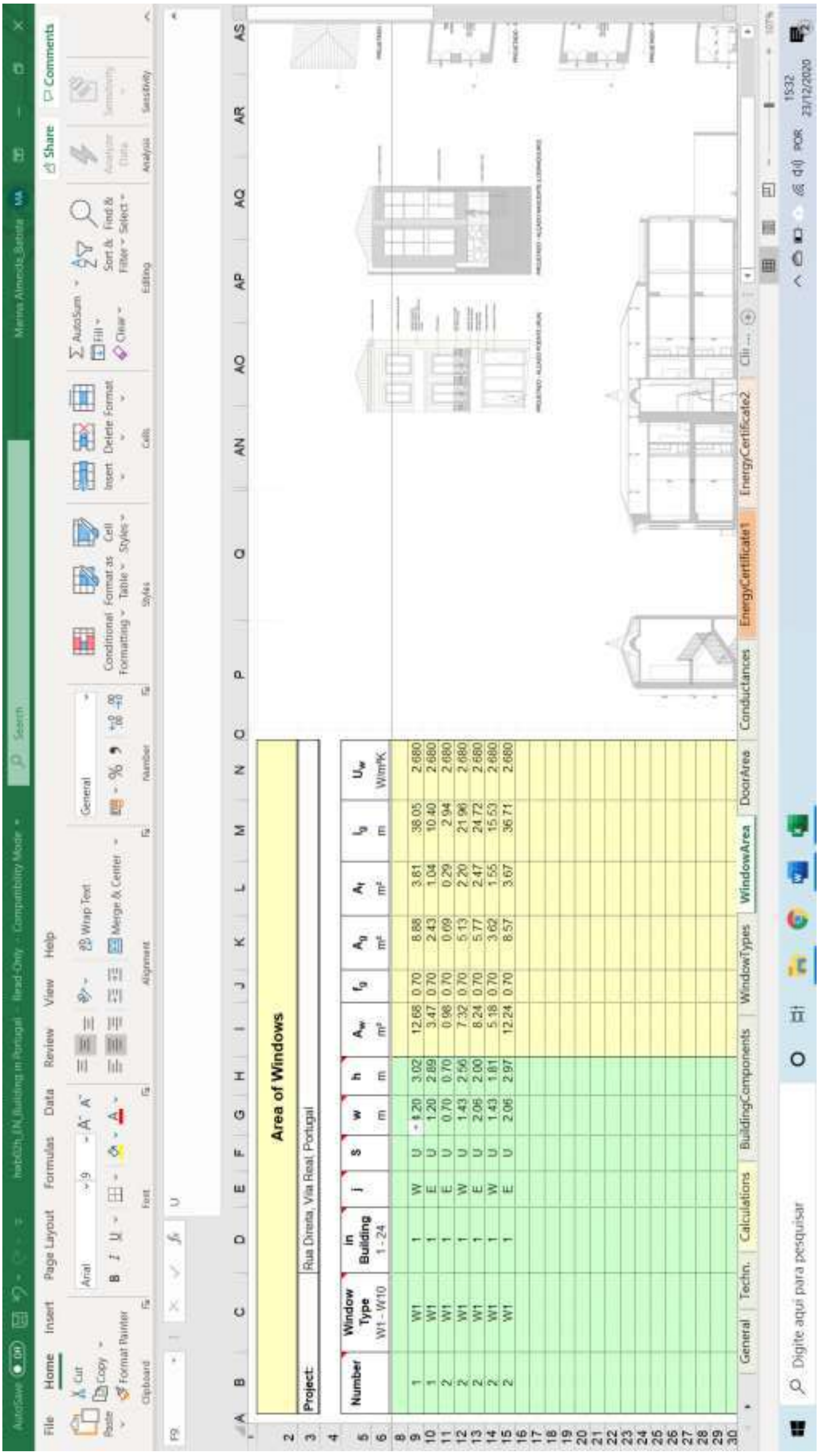




temperature correction factor f_i
0.9
Comp. 3
Exterior Ceiling
exterior ceiling
U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K
U-Wert-Berechnung gemäß Schichtaufbau
No.
Layers
inside to outside
thickn. cm
part 1 %
part 2 %
λ 1 W/mK
λ 2 W/mK
d/λ m²K/W
1 Wood Planks 2.0 100 0.18 0.111
2 Wook Lathes (half wood half air) 10.0 50 50.00 0.18 10.00 0.556
3 Wood Planks 2.0 100 0.18 0.111
4 There's probably an extra protection layer but I couldn't find exactly wh
heat transition resistance in m²K/W
down: without rear ventilation
0.210
heat transfer resistance in m²K/W
0.988
0.988
0.988
3 homogeneous layers
total thickness of construction: 14 cm
heat transfer coefficient U_i in W/m²K
1.012
temperature correction factor f_i
1.0
Comp. 4
FLOOR to ground
floor to ground
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2


Comp. 4
FLOOR to ground
floor to ground
U-Wert laut Gutachten gemäß EN ISO 6946 in W/m²K
U-Wert-Berechnung gemäß Schichtaufbau
No.
Layers
inside to outside
thickn.
cm
part 1
%
part 2
%
λ 1
W/mK
λ 2
W/mK
d/λ
m²K/W
1 Wood flooring 2.5 100 0.18 0.139
2 Gravel 10.0 100 2.80 0.036
3 Stones 15.0 100 2.80 0.054
heat transition resistance $R_{si} + R_{se}$ in m²K/W 0.170
heat transfer resistance R_T' in m²K/W 0.398
heat transfer resistance R_T'' in m²K/W 0.398
$R_T = (R_T' + R_T'') / 2$ in m²K/W 0.398
3 homogeneous layers
total thickness of construction: 27.5 cm
heat transfer coefficient U_i in W/m²K 2.511
temperature correction factor f_i 0.5
Comp. 5
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2

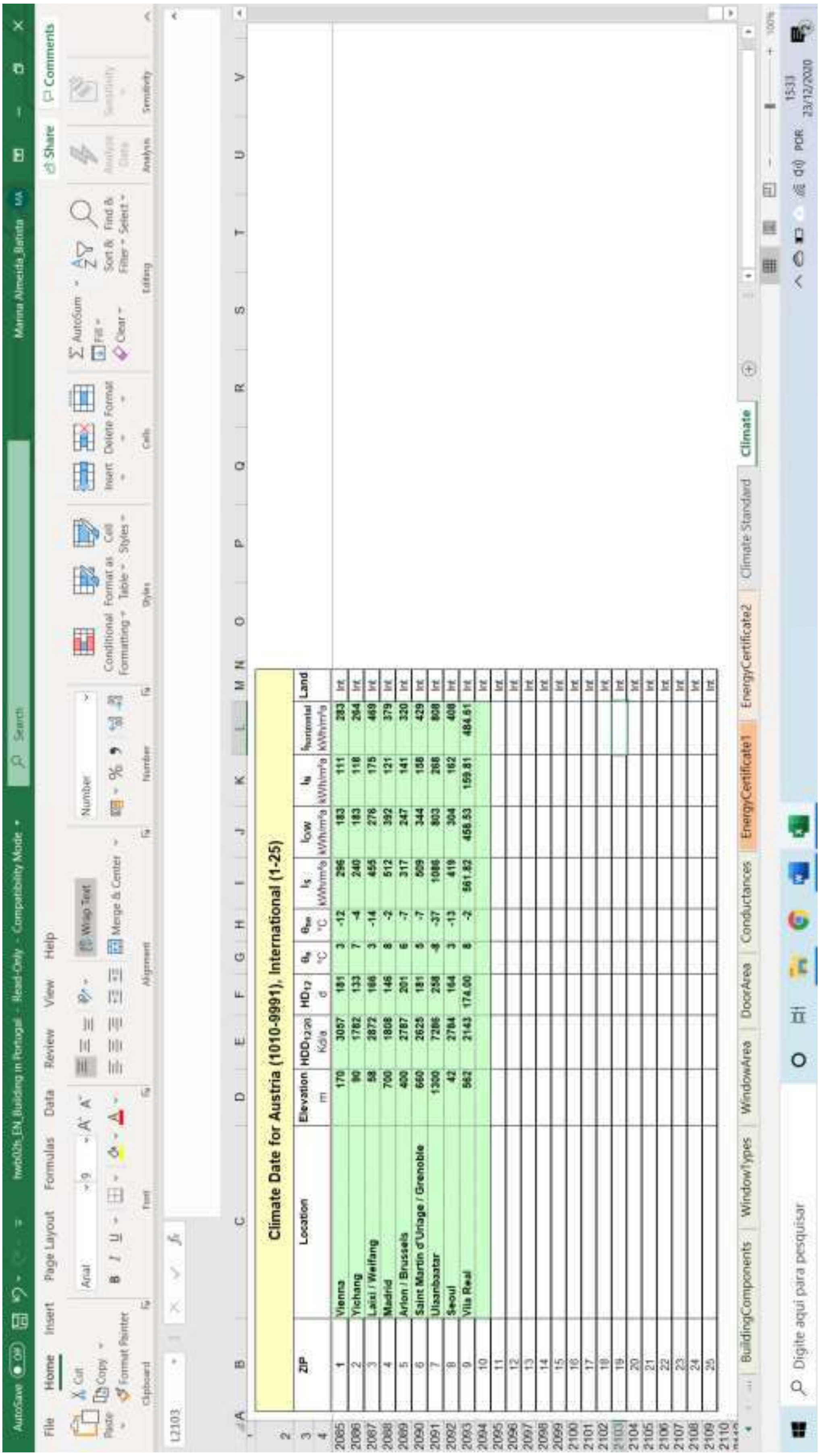

Windows
Project
Rua Direita, Vila Real, Portugal
Window W1
All WINDOWS (old double glazing, standard g-value)
U-Value of window U_w according to certificate in W/m²K
U-Value of glazing U_g in W/m²K
U-Value of frame U_f in W/m²K
thermal bridge coefficient ψ_g in W/mK
total energy transmittance g-Value
2.800
2.000
0.040
0.800
Window W2
Window W3
General
Techn.
Calculations
BuildingComponents
WindowTypes
WindowArea
DoorArea
Conductances
EnergyCertificate1
EnergyCertificate2



Area of Windows

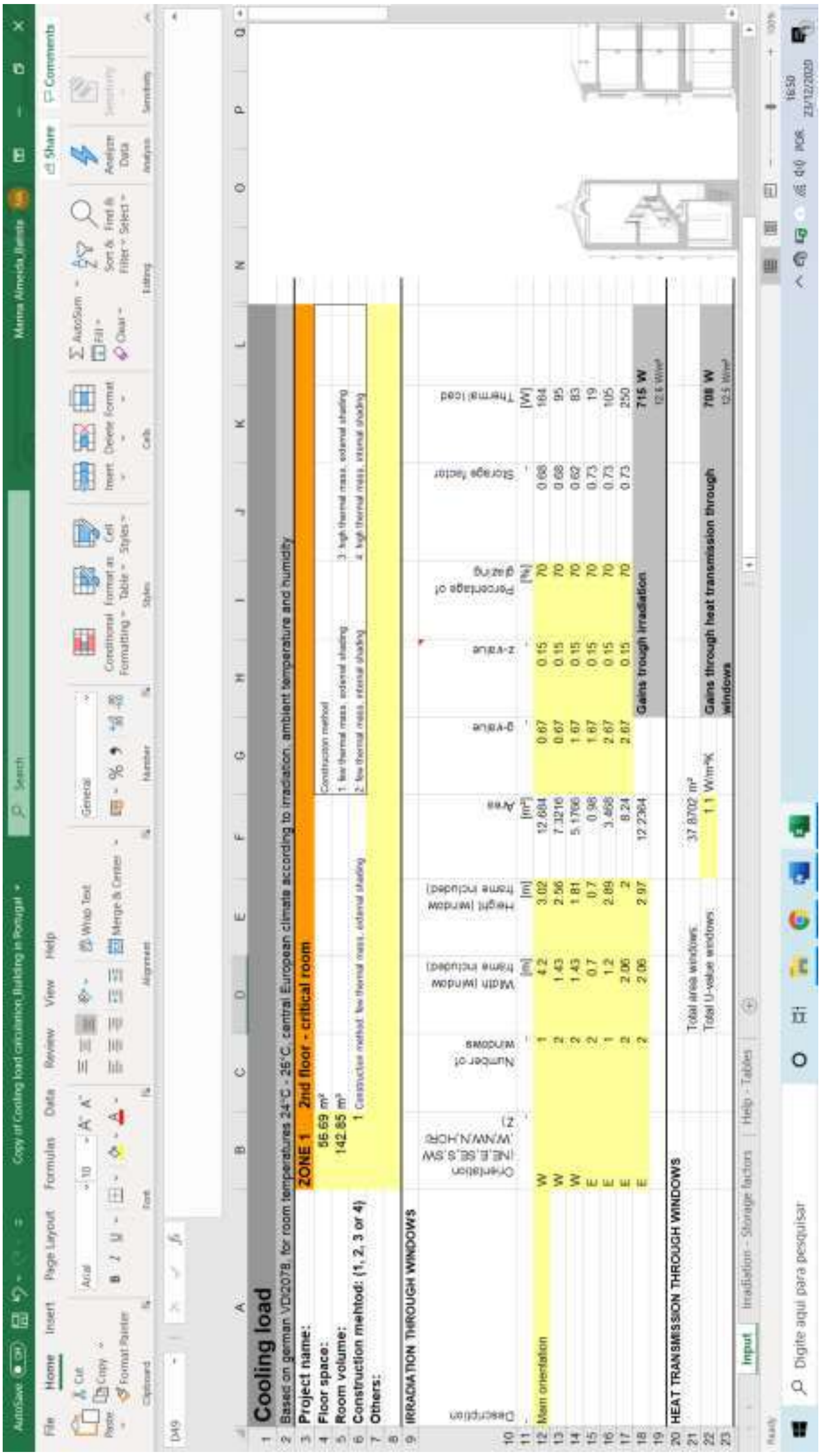
Project: Rua Direita, Vila Real, Portugal

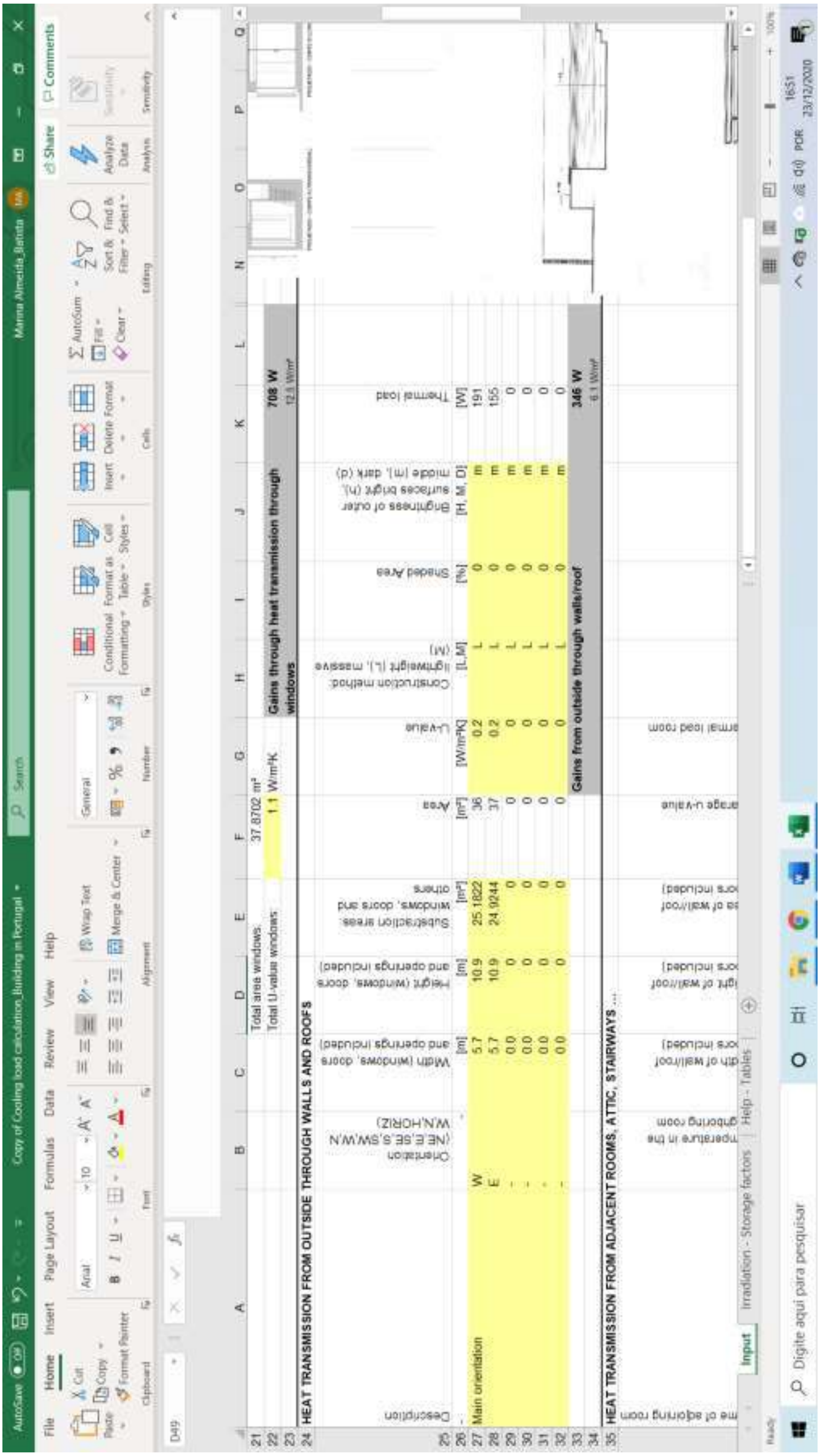
Number	Window Type	In Building	j	s	w	h	A_w	f_g	A_g	A_f	l_g	U_w
	W1 - W10	1 - 24			m	m	m²		m²	m²	m	W/m²K
1	W1	1	W	U	1.20	3.02	12.68	0.70	8.88	3.81	38.05	2.680
1	W1	1	E	U	1.20	2.89	3.47	0.70	2.43	1.04	10.40	2.680
2	W1	1	E	U	0.70	0.70	0.98	0.70	0.69	0.29	2.94	2.680
2	W1	1	W	U	1.43	2.56	7.32	0.70	5.13	2.20	21.96	2.680
2	W1	1	E	U	2.06	2.00	8.24	0.70	5.77	2.47	24.72	2.680
2	W1	1	W	U	1.43	1.81	5.18	0.70	3.62	1.55	15.53	2.680
2	W1	1	E	U	2.06	2.97	12.24	0.70	8.57	3.67	36.71	2.680

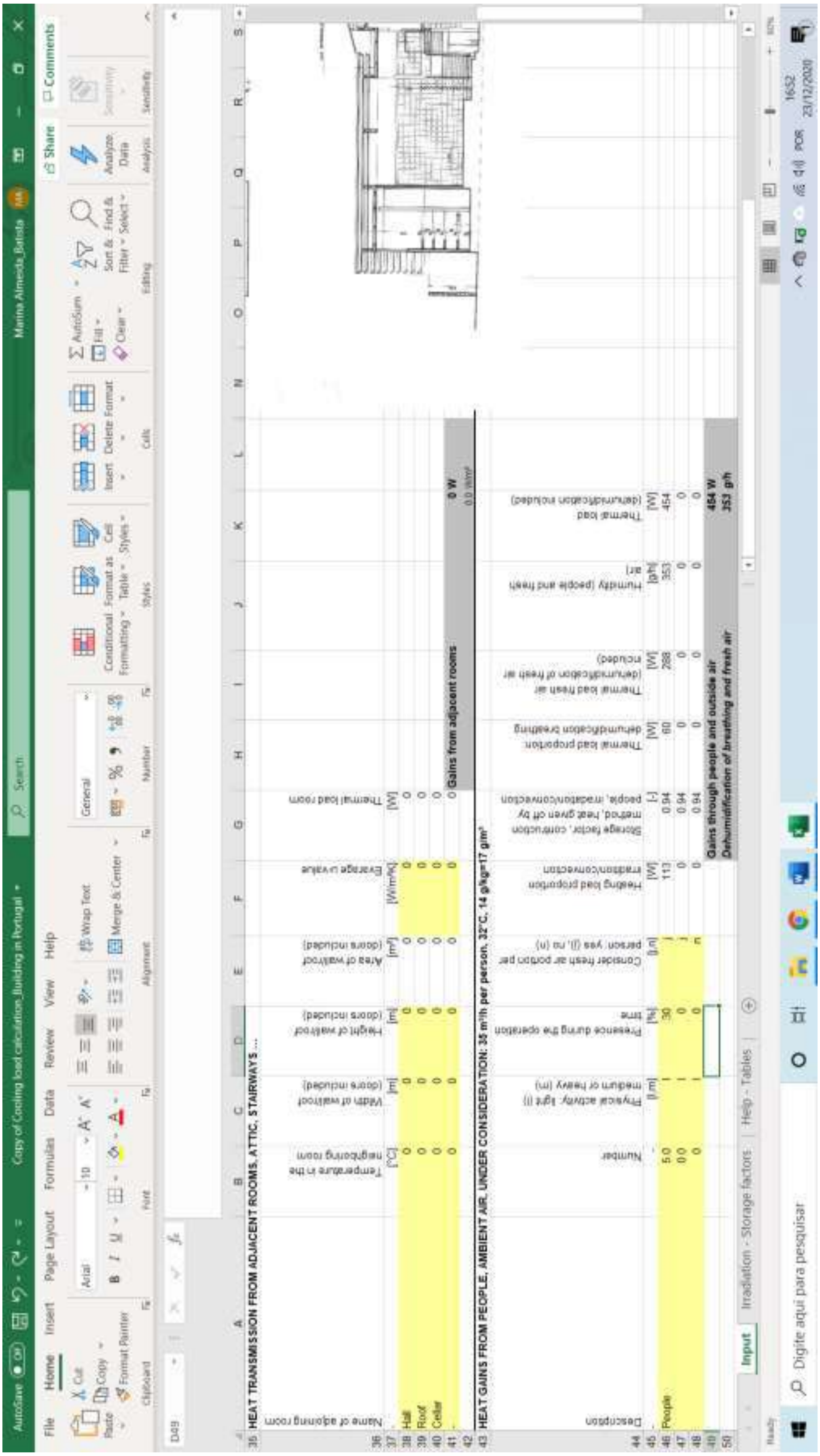


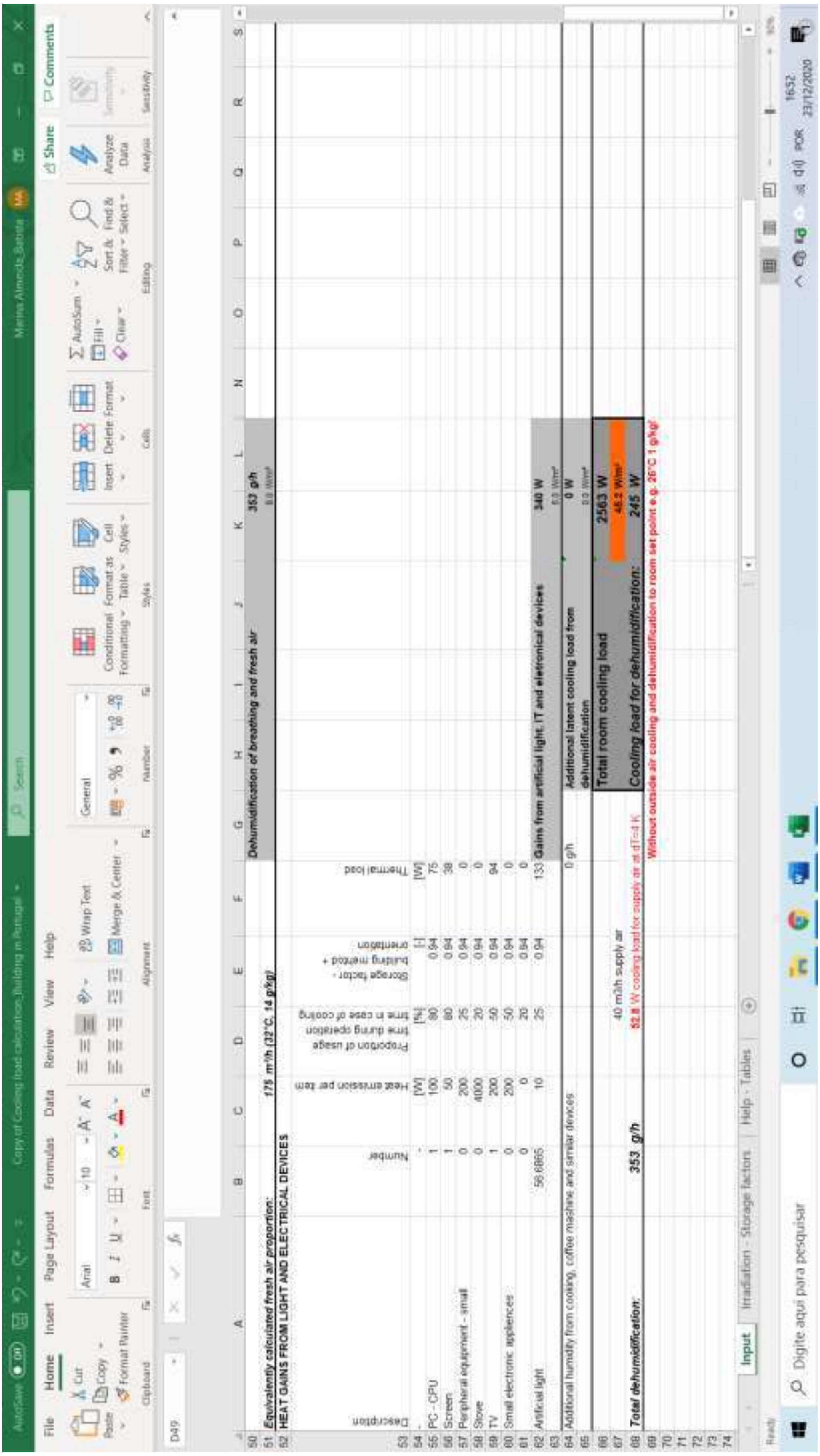
ZIP	Location	Elevation m	$HDD_{12/20}$ Kd/a	HD_{12} d	θ_e °C	θ_{ne} °C	I_S kWh/m²a	$I_{O/W}$ kWh/m²a	I_N kWh/m²a	$I_{horizontal}$ kWh/m²a	Land
1	Vienna	170	3057	181	3	-12	296	183	111	283	Int
2	Yichang	90	1782	133	7	-4	240	183	118	264	Int
3	Laixi / Weifang	58	2872	166	3	-14	455	276	175	469	Int
4	Madrid	700	1808	146	8	-2	512	392	121	379	Int
5	Arlon / Brussels	400	2787	201	6	-7	317	247	141	320	Int
6	Saint Martin d'Uriage / Grenoble	660	2625	181	5	-7	509	344	158	429	Int
7	Ulaanbaatar	1300	7286	258	-8	-37	1086	803	268	808	Int
8	Seoul	42	2784	164	3	-13	419	304	162	408	Int
9	Vila Real	562	2143	174.00	8	-2	561.82	458.53	159.81	484.61	Int
10											Int
11											Int
12											Int
13											Int
14											Int
15											Int
16											Int
17											Int
18											Int
19											Int
20											Int
21											Int
22											Int
23											Int
24											Int
25											Int

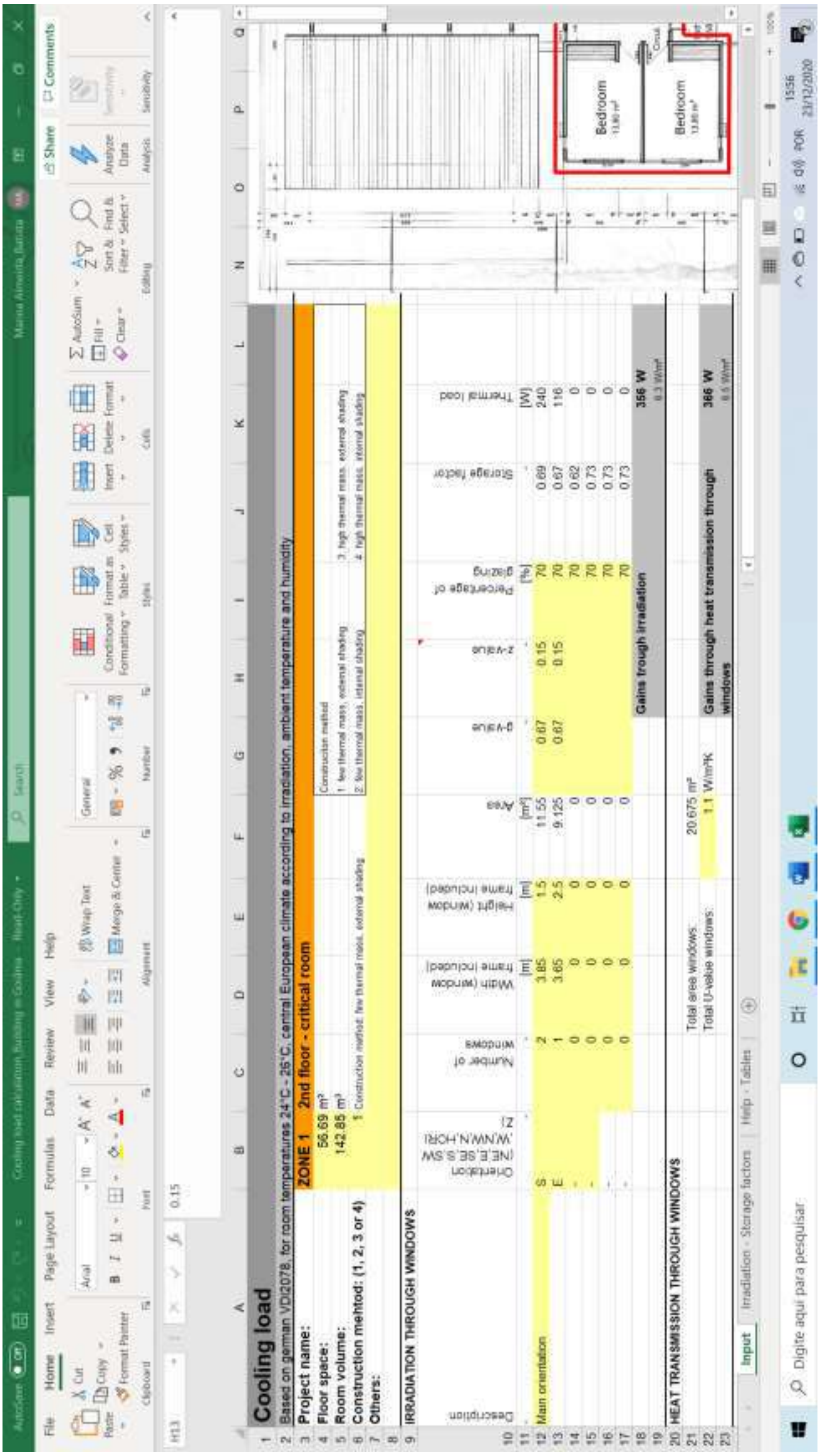
ANNEX 3 – COOLING CALCULATION – VILA REAL AND GOIÂNIA

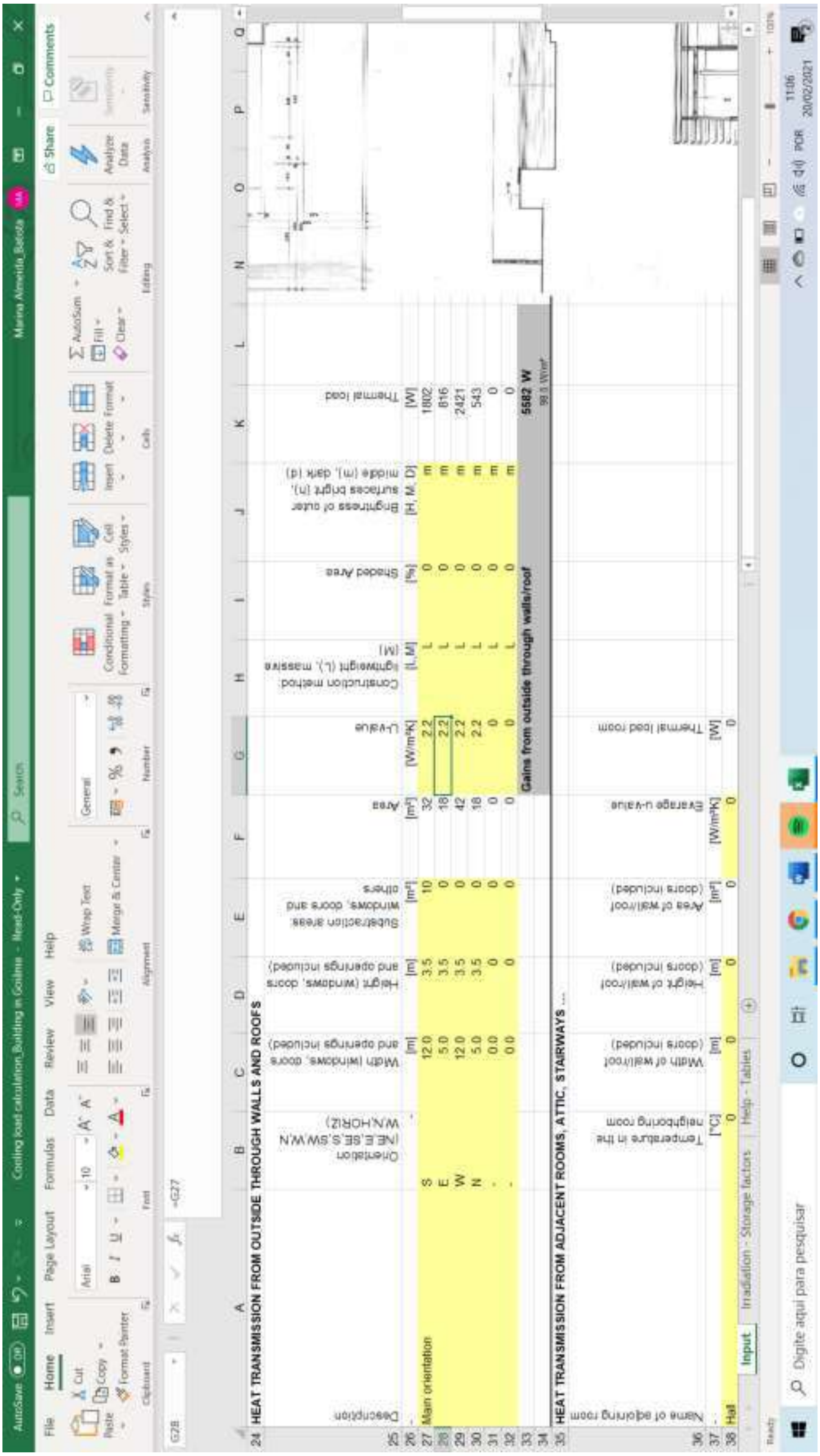


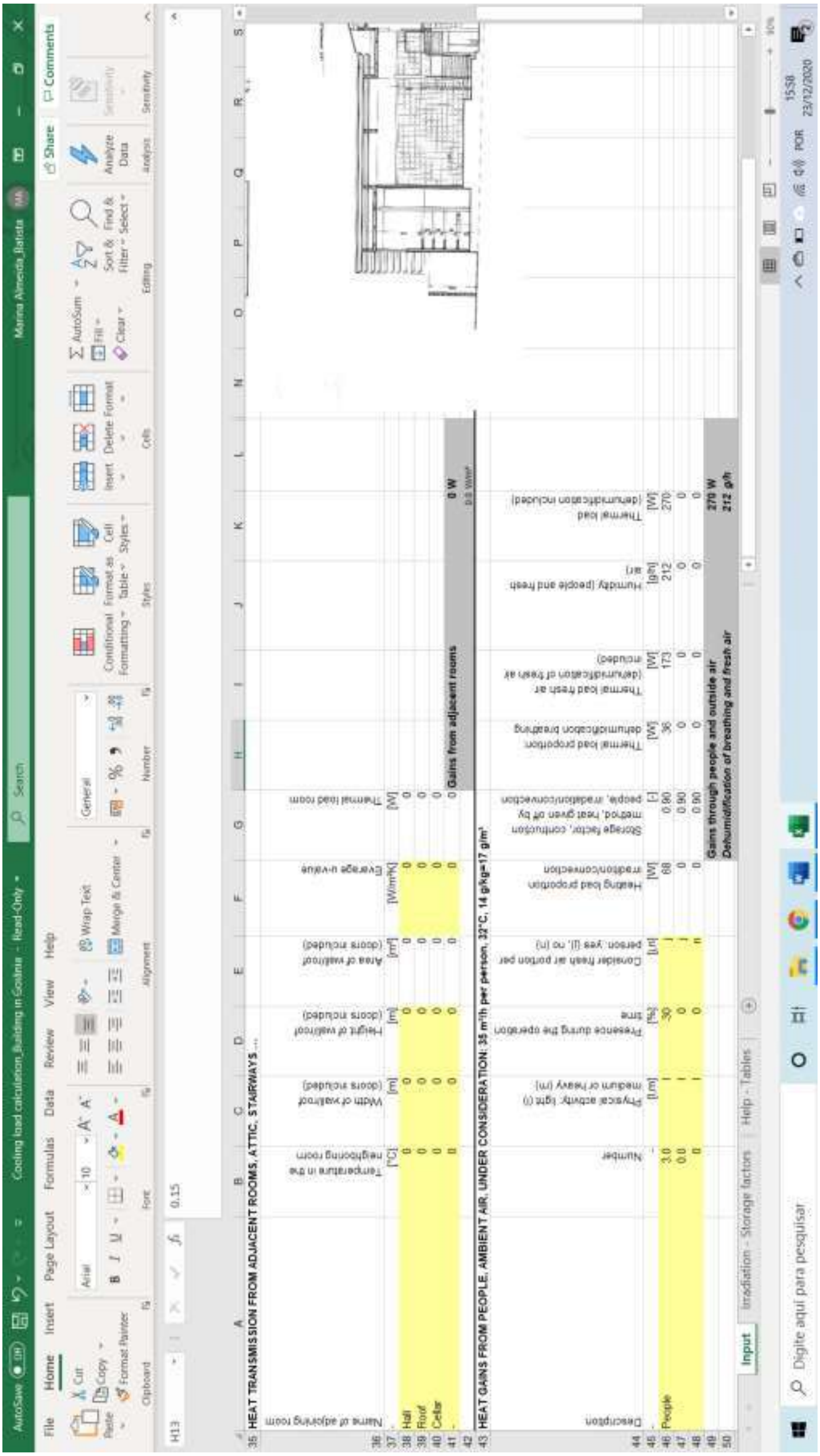

HEAT TRANSMISSION FROM OUTSIDE THROUGH WALLS AND ROOFS
Gains through heat transmission through windows
708 W
Gains from outside through walls/roof
346 W
HEAT TRANSMISSION FROM ADJACENT ROOMS, ATTIC, STAIRWAYS ...
Main orientation

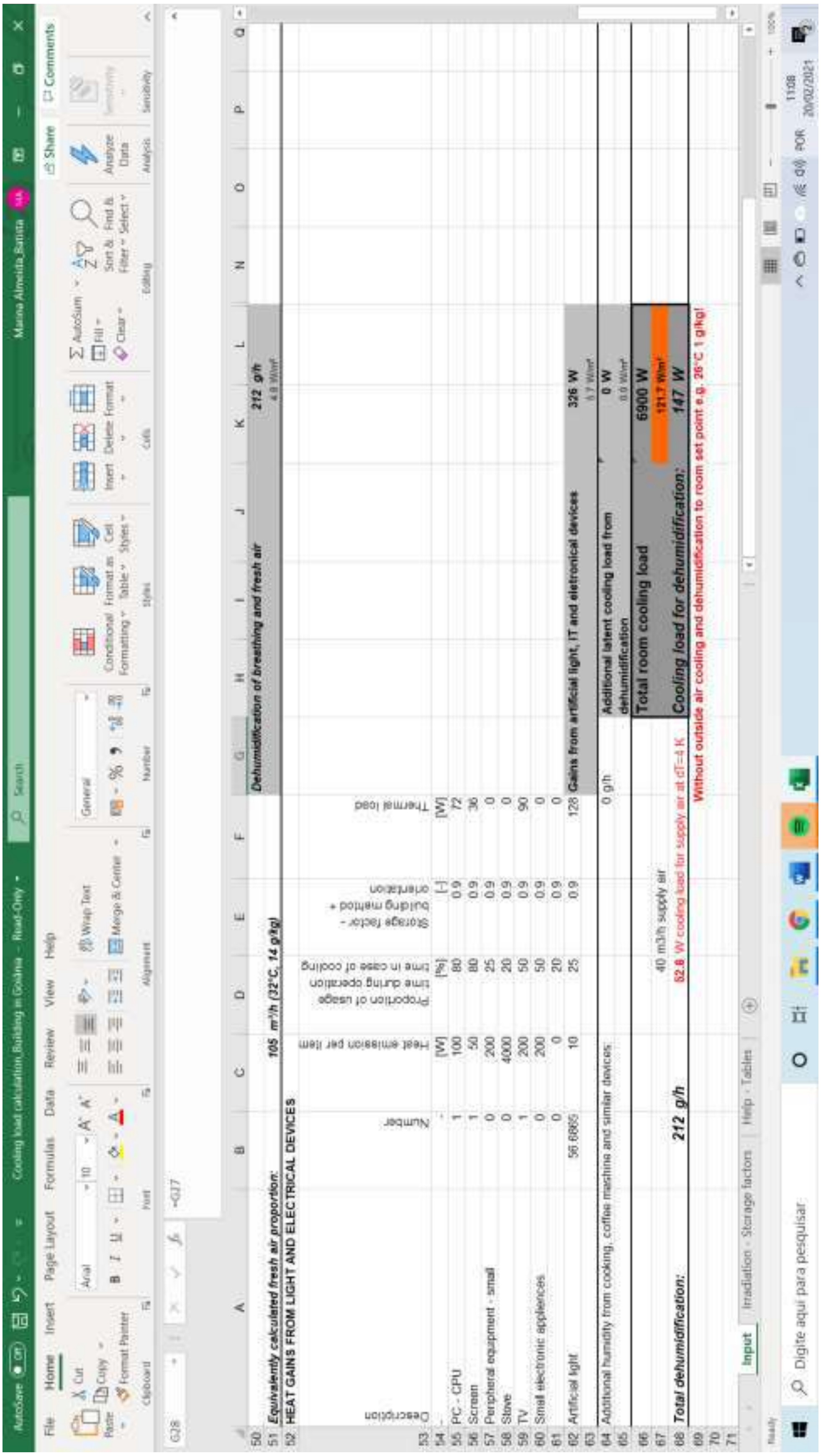

Copy of Cooling load calculation_Building in Portugal
HEAT TRANSMISSION FROM ADJACENT ROOMS, ATTIC, STAIRWAYS ...
Name of adjoining room
Temperature in the neighboring room
Width of wall/roof (doors included)
Height of wall/roof (doors included)
Area of wall/roof (doors included)
Everage U-value
Thermal load room
Hall
Roof
Cellar
Gains from adjacent rooms
0 W
HEAT GAINS FROM PEOPLE, AMBIENT AIR, UNDER CONSIDERATION: 35 m³/h per person, 32°C, 14 g/kg=17 g/m³
Description
Number
Physical activity: light (l) medium or heavy (m)
Presence during the operation time
Consider fresh air portion per person: yes (j), no (n)
Heating load proportion: iradiation/convection
Storage factor, contruction method, heat given off by people, iradiation/convection
Thermal load proportion: dehumidification breathing
Thermal load fresh air (dehumidification of fresh air included)
Humidity (people and fresh air)
Thermal load (dehumidification included)
People
Gains through people and outside air
454 W
Dehumidification of breathing and fresh air
353 g/h
Input
Irradiation - Storage factors
Help - Tables


Equivalently calculated fresh air proportion:
175 m³/h (32°C, 14 g/kg)
HEAT GAINS FROM LIGHT AND ELECTRICAL DEVICES
Dehumidification of breathing and fresh air
353 g/h
Description
Number
Heat emission per item
Proportion of usage time during operation time in case of cooling
Storage factor - building method + orientation
Thermal load
PC - CPU
Screen
Peripheral equipment - small
Stove
TV
Small electronic appliences
Artificial light
Gains from artificial light, IT and eletronical devices
340 W
Additional humidity from cooking, coffee machine and similar devices
Additional latent cooling load from dehumidification
0 W
Total room cooling load
2563 W
Total dehumidification:
353 g/h
40 m³/h supply air
Cooling load for dehumidification:
245 W
Without outside air cooling and dehumidification to room set point e.g. 26°C 1 g/kg
Input
Irradiation - Storage factors
Help - Tables

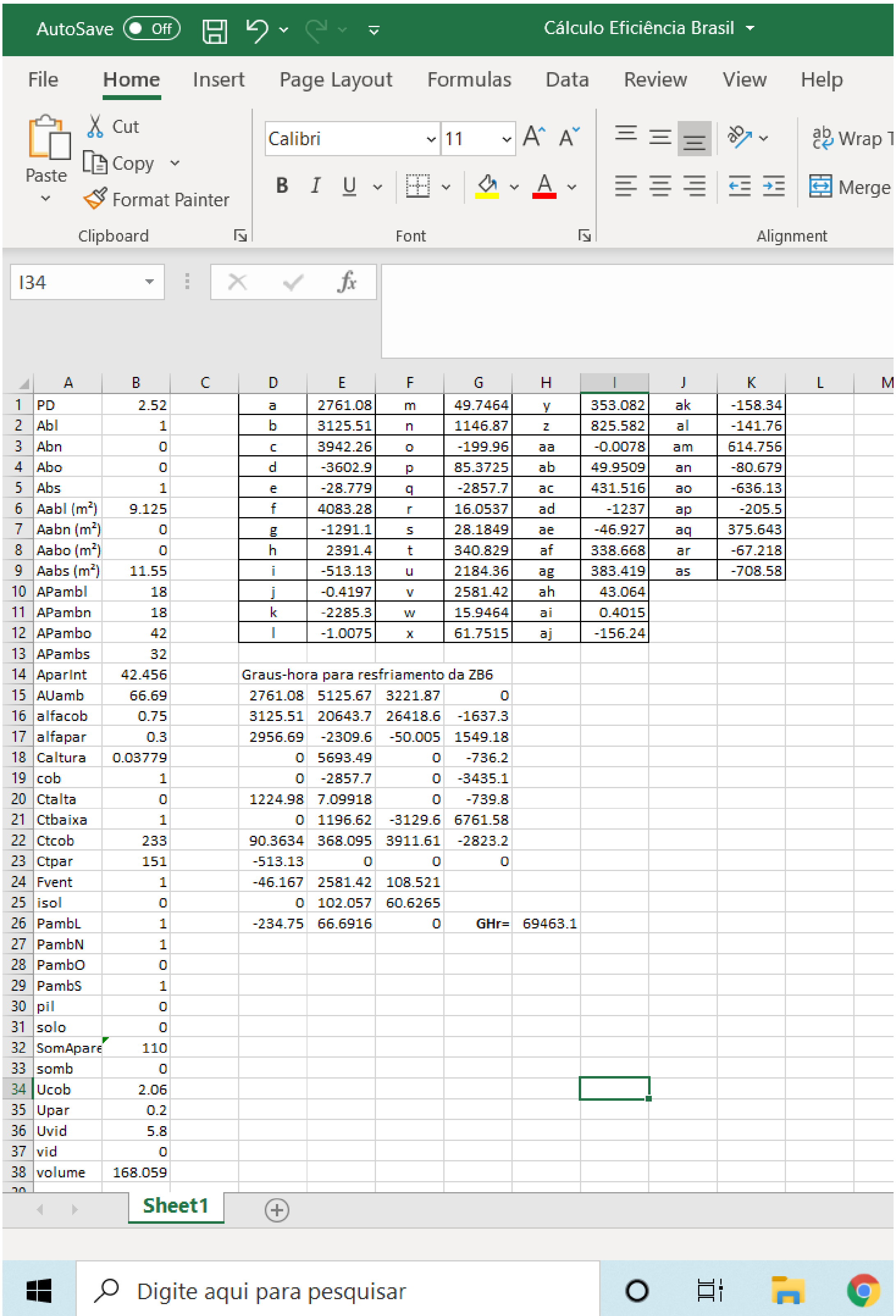

Cooling load
Based on german VDI2078, for room temperatures 24°C - 26°C, central European climate according to irradiation, ambient temperature and humidity
Project name:
ZONE 1
2nd floor - critical room
Floor space:
56.69 m²
Room volume:
142.85 m³
Construction mehtod: (1, 2, 3 or 4)
Others:
IRRADIATION THROUGH WINDOWS
HEAT TRANSMISSION THROUGH WINDOWS
Gains trough irradiation
356 W
Gains through heat transmission through windows
366 W
Bedroom
Bedroom


HEAT TRANSMISSION FROM OUTSIDE THROUGH WALLS AND ROOFS
Description
Orientation (N,E,S,SE,S,SW,W,N,W,N,HORIZ)
Width (windows, doors and openings included)
Height (windows, doors and openings included)
Subtraction areas windows, doors and others
Area
U-value
Construction method lightweight (L), massive (M)
Shaded Area
Brightness of outer surfaces bright (H), middle (M), dark (D)
Thermal load
Main orientation
Gains from outside through walls/roof
5582 W
HEAT TRANSMISSION FROM ADJACENT ROOMS, ATTIC, STAIRWAYS ...
Name of adjoining room
Temperature in the neighboring room
Width of wall/roof (doors included)
Height of wall/roof (doors included)
Area of wall/roof (doors included)
Everage u-value
Thermal load room
Hall
Input
Irradiation - Storage factors
Help - Tables


HEAT TRANSMISSION FROM ADJACENT ROOMS, ATTIC, STAIRWAYS ...
Gains from adjacent rooms
HEAT GAINS FROM PEOPLE, AMBIENT AIR, UNDER CONSIDERATION: 35 m³/h per person, 32°C, 14 g/kg=17 g/m³
Gains through people and outside air
Dehumidification of breathing and fresh air
270 W
212 g/h


Cooling load calculation_Building in Coimbra - Read-Only
Equivalently calculated fresh air proportion:
105 m³/h (32°C, 14 g/kg)
Dehumidification of breathing and fresh air
212 g/h
4.8 W/m²
HEAT GAINS FROM LIGHT AND ELECTRICAL DEVICES
Description
Number
Heat emission per item
Proportion of usage time during operation time in case of cooling
Storage factor - building method + orientation
Thermal load
PC - CPU
Screen
Peripheral equipment - small
Stove
TV
Small electronic appliences
Artificial light
56.6865
Gains from artificial light, IT and eletronical devices
326 W
6.7 W/m²
Additional humidity from cooking, coffee machine and similar devices:
0 g/h
Additional latent cooling load from dehumidification
0 W
0.0 W/m²
Total room cooling load
6900 W
121.7 W/m²
Total dehumidification:
212 g/h
40 m³/h supply air
82.8 W cooling load for supply air at dT=4 K
Cooling load for dehumidification:
147 W
Without outside air cooling and dehumidification to room set point e.g. 26°C 1 g/kg!
Input
Irradiation - Storage factors
Help - Tables

ANNEX 4 – CALCULATIONS OF DEGREE-HOURS - GOIÂNIA



	A	B	C	D	E	F	G	H	I	J	K
1	PD	2.52		a	2761.08	m	49.7464	y	353.082	ak	-158.34
2	Abl	1		b	3125.51	n	1146.87	z	825.582	al	-141.76
3	Abn	0		c	3942.26	o	-199.96	aa	-0.0078	am	614.756
4	Abo	0		d	-3602.9	p	85.3725	ab	49.9509	an	-80.679
5	Abs	1		e	-28.779	q	-2857.7	ac	431.516	ao	-636.13
6	Aabl (m²)	9.125		f	4083.28	r	16.0537	ad	-1237	ap	-205.5
7	Aabn (m²)	0		g	-1291.1	s	28.1849	ae	-46.927	aq	375.643
8	Aabo (m²)	0		h	2391.4	t	340.829	af	338.668	ar	-67.218
9	Aabs (m²)	11.55		i	-513.13	u	2184.36	ag	383.419	as	-708.58
10	APambl	18		j	-0.4197	v	2581.42	ah	43.064		
11	APambn	18		k	-2285.3	w	15.9464	ai	0.4015		
12	APambo	42		l	-1.0075	x	61.7515	aj	-156.24		
13	APambs	32									
14	AparInt	42.456		Graus-hora para resfriamento da ZB6							
15	AUamb	66.69		2761.08	5125.67	3221.87	0				
16	alfacob	0.75		3125.51	20643.7	26418.6	-1637.3				
17	alfapar	0.3		2956.69	-2309.6	-50.005	1549.18				
18	Caltura	0.03779		0	5693.49	0	-736.2				
19	cob	1		0	-2857.7	0	-3435.1				
20	Ctalta	0		1224.98	7.09918	0	-739.8				
21	Ctbaixa	1		0	1196.62	-3129.6	6761.58				
22	Ctcob	233		90.3634	368.095	3911.61	-2823.2				
23	Ctpar	151		-513.13	0	0	0				
24	Fvent	1		-46.167	2581.42	108.521					
25	isol	0		0	102.057	60.6265					
26	PambL	1		-234.75	66.6916	0	GHr=	69463.1			
27	PambN	1									
28	PambO	0									
29	PambS	1									
30	pil	0									
31	solo	0									
32	SomApare	110									
33	somb	0									
34	Ucob	2.06									
35	Upar	0.2									
36	Uvid	5.8									
37	vid	0									
38	volume	168.059									