UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Architecture

Integrating Passivhaus Principles with Local Climate Considerations: Energy-Efficient Buildings for the Weather Conditions in Oklahoma (US)

End of Degree Project

Bachelor's Degree in the Fundamentals of Architecture

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ABSTRACT

The “Passivhaus” standard aims to minimize the energy consumption of buildings based on passive design principles. This approach leads to the creation of buildings that are highly energy efficient, as well as more sustainable and economically viable in the long term. This practice is widespread in many regions of the world, but the Southwest Central United States is not one of them. Within this large area, the state of Oklahoma stands out for experiencing a diverse climate with hot summers and cool winters, along with other weather phenomena that characterize it (severe thunderstorms, tornadoes, freezing rain, heatwaves…). In addition, local conventional construction does not tend to prioritize energy efficiency, which generates a constant situation of high demand and consumption in its buildings. Considering the above, this work aims to adapt the Passivhaus standard in the state of Oklahoma, focusing on developing strategies to implement it in the single-family housing typology. (150 words)

KEYWORDS: Sustainable architecture, Energy efficiency, Passivhaus, Passive design, Climate-responsive design

RESUMEN

El estándar “Passivhaus” tiene como objetivo principal minimizar el consumo energético de los edificios basándose en principios de diseño pasivo. Este enfoque conduce a la creación de construcciones con una alta eficiencia energética, además de más sostenibles y económicamente viables a largo plazo. Esta práctica está extendida en muchas regiones del mundo, pero el Centro Suroeste de Estados Unidos no es una de ellas. Dentro de esta extensa zona, el estado de Oklahoma destaca por experimentar un clima complejo con veranos calurosos, inviernos fríos y otros fenómenos meteorológicos que lo caracterizan (tormentas severas, tornados, lluvia helada, olas de calor...). Además, la arquitectura convencional de este lugar no tiende a priorizar la eficiencia energética, lo cual genera una situación constante de elevada demanda y consumo en sus edificios. Teniendo en cuenta lo anterior, este trabajo tiene como objetivo la adaptación del estándar “Passivhaus” en el estado de Oklahoma, centrándose en desarrollar estrategias para implementarlo en la tipología de vivienda unifamiliar. (159 palabras)

PALABRAS CLAVE: Arquitectura sostenible, Eficiencia energética, Passivhaus, Diseño pasivo, Diseño adaptado al clima

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1. INTRODUCTION

1.1. Background and motivation

The issue of climate change is a reality that has ceased to be deniable in today's context, as is the crucial role played by architecture and the entire industry surrounding it in this regard. Now more than ever, an increasing number of professionals are committing to the pursuit of creating architecture that is both sustainable and environmentally responsible, while regulatory measures to ensure this are becoming progressively more stringent. Consequently, it is noteworthy that green product standards have been present in the marketplace since the 1980s and are consistently expanding in both breadth and quantity. The discourse surrounding green certifications and standards (e.g., BREEAM, LEED, Green Gloves, etc.) and the integration of renewable technologies has progressively become commonplace, aiming to steer towards a more environmentally respectful built environment (Vierra, 2023).

Among the various certifications utilized in the realm of sustainable construction, the Passivhaus standard has garnered significant popularity in recent years. Essentially, this standard owes its acclaim to its stringent focus on energy efficiency, while simultaneously prioritizing user comfort. The Passivhaus standard is underpinned by principles aimed primarily at minimizing energy consumption, including thermal insulation, airtightness, and controlled ventilation with heat recovery (Wassouf, 2015). This standard was established in Germany, where it was defined in 1995 by Wolfang Feist, who subsequently founded the Passivhaus Institute (PHI) the following year to promote and institutionalize it (Ionescu et al., 2015). Since then, Passivhaus construction has spread worldwide, as seen in Figure 1, with the European continent boasting the highest number of certified buildings and the most extensive practical expertise.

Figure 1. World map of certified buildings (Source: Certified Buildings Map, 2024).

Similarly, upon further examination of Figure 1, it becomes evident that North America emerges as the next significant region where the Passivhaus standard enjoys relative proliferation, as indicated by the number of certified buildings shown in the map. Specifically, according to the Passive House Database (n.d.), as of the current date (April 4, 2024), the United States of America and Canada lead in the count of Passivhaus buildings in this region, with 143 and 98 constructions respectively, as reported by this source. In addition to these data, focusing on the United States of America as the primary proponent of the standard in this part of the world, three different organizations in this country are affiliated and officially recognized by the International Passive House Association (iPHA): The Passive House Network (PHN), New York Passive House (NYPH), and Passive House California (PHCa) (iPHA Affiliate Organisations, n.d.). With all the preceding contextualization, it can be asserted that the United States of America has been an active participant in the development of constructions adhering to the principles of the Passivhaus standard in recent years as presented in Figure 2.

Figure 2. Detail of the World map of certified buildings (Source: Certified Buildings Map, 2024).

However, upon closer examination of the United States territory in Figure 2, it becomes evident that the majority of activity related to the construction of Passivhaus-certified buildings is concentrated primarily in the northeast and west coast regions. To accurately refer to the different regions of the country, this paper will utilize the official division conducted by the U.S. Census Bureau (Census Regions and Divisions of the United States, 2013), depicted in Figure 3. Considering this cited division, the lack of such practices in the country's southern region, specifically in the West South Central division (Arkansas, Louisiana, Oklahoma, Texas), inevitably draws attention. This is because this particular area is recognized for the significant impact that "extreme temperature days" (Henderson, 1997, p.151) have on energy consumption and the comfort of its inhabitants, these being defined by Henderson (1997) as "a day that exceeds 1 standard deviation of the long-term average temperature for that day." (p.151). In particular, this paper will focus on the interest that the state of Oklahoma, situated within the aforementioned region, may have in the implementation of the Passivhaus standard, being considered particularly noteworthy for the above and other various reasons.

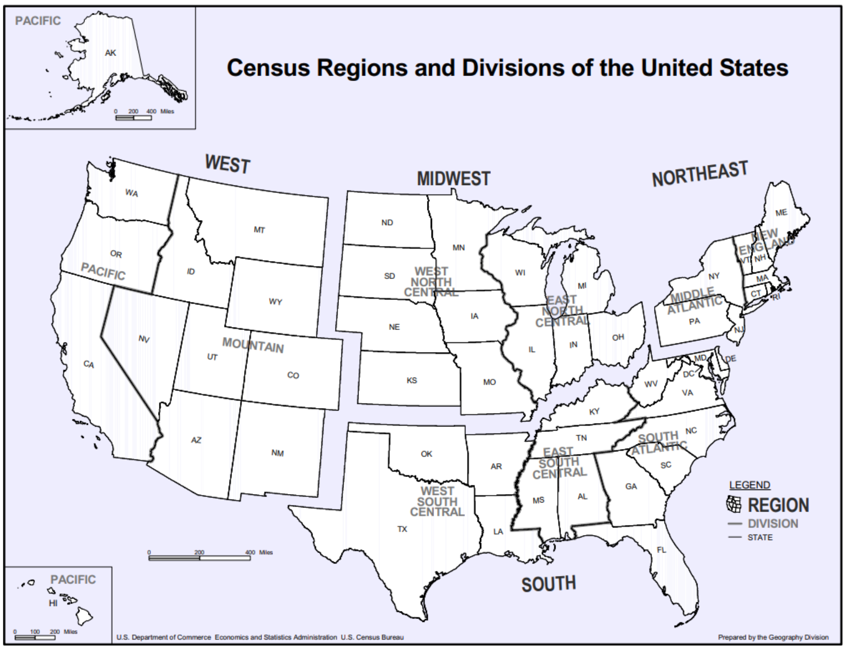


Figure 3. Census Regions and Divisions of the United States (Source: Census Regions and Divisions of the United States, 2013).

Besides being known for the aspects that characterize the West South Central division, the state of Oklahoma also has other traits that make it an interesting area where the integration of the Passivhaus standard could be potentially challenging but simultaneously have a greater impact. One of these additional aspects, undoubtedly of significant importance, is that Oklahoma has ranked among the states with the highest occurrence of natural disasters caused by severe weather phenomena (storms, hail, floods, etc.) since the 1950s. Furthermore, it is a state situated within the high-risk tornado zone, commonly known as tornado alley (Na-Yemeh, 2022). Another characteristic that renders it a particularly attractive locale for initiatives such as the one addressed in this paper is its imperative to progress in terms of energy efficiency, shown by its designation as the state with the lowest score regarding its energy efficiency policies for buildings in national reports (Subramanian et al., 2022). Moreover, the median household income in the state of Oklahoma has remained below the national average in recent years (Guzman, 2022), which could also be indicative of its need to mitigate the high costs associated with energy consumption in its households through the implementation of the Passivhaus standard.

1.2. Objectives of the Final Degree Project

The primary objective of this paper is to develop a construction solution that facilitates the integration of the Passivhaus standard in the state of Oklahoma, United States, tailored to the local conditions and requirements. Specifically, the aim is to propose a construction solution for single-family housing that adheres to the principles of the standard, in addition to adapting to the most common construction practices and types of housing in the area.

To achieve this goal, preliminary research is conducted on the Passivhaus standard, as well as on the parameters that will determine its potential integration in the selected territory as a case study. The intention is to gather the necessary information to establish a solid foundation for this endeavor and to formulate a proposal that aligns with the needs and possibilities of the state of Oklahoma. From this point on, the completed proposal should meet the criteria established by the German standard most suitably and sustainably.

In this way, this paper intends to provide as much information as possible about the possibilities to be explored in the field of housing construction in a state known for the absence of practices of this type when compared to other regions of the country.

1.3. Methodology

The process followed in this paper for the adaptation of the Passivhaus Standard to the climate and circumstances of the state of Oklahoma, USA, is structured in several phases. All of these are necessary to achieve an optimal result and are structured as follows.

Aiming to develop a model house project that meets the requirements of the standard in this place where there is no building of these characteristics at present, the first part of the process is based on contextualizing and understanding the field of study to be addressed. For this, the first task is to research the standard itself, so that its requirements and recommendations are clear, as well as the process to follow when a dwelling is to be certified by it. Similarly, information about Oklahoma is required to better comprehend the social and architectural setting and to identify local features that may influence the acceptance and adaptation of the standard. Naturally, a climate study and collection of more specific data on existing housing stock is needed as well.

Then, once all the information gathered through the research has been analyzed, the next step is to propose a model house that responds to the identified local needs. For this purpose, specific construction solutions are selected for the house and adapted to the area's available resources, integrating all the necessary elements to follow the premises of an energy-efficient house.

The final stage involves analyzing and verifying this proposed solution. By using the tools provided by the standard, such as the PHPP, a simulation of the building is created for calculating its energy demand values and testing the adjustment of these to the established limits. Once these results have been studied, the potential and the gaps in the adaptation of the standard to this specific location become more evident.

2. THE PASSIVHAUS STANDARD

2.1. Overview of Passivhaus Standard

Over the past several decades, the pressing issue of climate change has necessitated the exploration of various strategies aimed at reducing the energy consumption of buildings. These strategies have primarily focused on the optimization of pre-existing systems or the application of renewable energy sources. However, they have not generally pursued a fundamental reinterpretation of the concept behind the buildings. Instead, they have focused on specific improvements that often resulted in budget increases or even the appearance of additional problems (Feist et al., 2005).

In this context, the "Passivhaus" concept emerged in 1988, introduced by Bo Adamson and Wolfgang Feist, Swedish and German professors, respectively. This proposal had been based, among other things, on the efficient housing models previously experimented in North America (Ionescu et al., 2015). The materialization of this idea would occur with the construction in 1990 of what are considered to be the first Passivhaus residential units in Darmstadt, Germany, and the subsequent creation in 1996 of the Passive House Institute. Monitoring this first project would be crucial to validate the concept, as well as to demonstrate its efficacy and highlight its future possibilities (Wang et al., 2017).

Since its inception, the primary objective of the Passivhaus standard has been to minimize the energy demand of buildings while ensuring the thermal comfort necessary for habitability and maintaining optimal indoor air quality. To achieve this, the standard focuses on reducing heating and cooling needs through stringent control of ventilation and thermal transmission losses, alongside maximizing gains from passive solar systems. The fundamental basis of the standard posits that indoor air temperature and quality can be sustained by slightly heating it within the ventilation system, thereby avoiding the need for a traditional central heating system. Although some active systems are permitted, the design parameters of buildings adhering to this standard are predominantly governed by passive design elements, including solar exposure, airtightness, and thermal insulation (Sameni et al., 2015).

As of 2024, more than 44,000 buildings worldwide are known to have received Passivhaus certification from the Passive House Institute (The global Passive House platform, n.d.). This significant figure reflects how this standard has gained popularity and spread internationally in recent decades, showing a positive reception since its appearance.

2.2. Key Components of the Passivhaus Standard

The official definition of the standard provided by the Passivhaus Institut is as follows: "A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air." (The Passive House - definition, n.d.). By thoroughly examining this definition, we can better comprehend the requirements governing the regulated aspects of heating and cooling loads, irrespective of climate. This understanding also elucidates the ideology behind the standard, which focuses on minimizing energy consumption through the low energy demand provided by the features of passive architecture (Wassouf, 2015).

Considering this context, it is crucial to recognize that beyond the aforementioned climate-independent requirements for heating and cooling, there are several criteria that the Passivhaus Institut has established for any building seeking certification. These criteria are categorized by (Wassouf, 2015) into two groups based on their relevance: 'direct criteria' and 'indirect criteria'. While the direct criteria are mandatory for certification, the indirect criteria are defined to achieve the comfort and hygiene parameters and can be modified if justified.

This paper will focus mainly on the three mandatory requirements for Passivhaus certification, the expected characteristics of a building designed under this standard, and the primary tool needed in the process.

2.2.1. Requirements for Certification

Any project, residential or otherwise, that seeks Passivhaus certification must undergo an evaluation process by the Passivhaus Institut, examining a comprehensive list of aspects. Among the numerous facets expected of such a building, the German organization sets three direct requirements to determine the project's validity for certification (Ionescu et al., 2015). The first two regulate the energy needed for interior space conditioning, while the third ensures that overall consumption remains within limits for the other additional services that increase energy demand (Dequaire, 2012).

Firstly, the maximum energy value to meet the annual space heating demand is capped at 15kWh/m2y. This practical value used as a limit, established by the Passivhaus Institut for Central European regions, cannot be explained through physical formulas. According to the Institut's official definition, this translates into a maximum annual power supplied for indoor air conditioning set at 10 W/m2 (Johnston et al., 2020). This criterion implies significantly low transmittance elements will be required for the building envelope to minimize heat loss. Besides the aforementioned, these values also translate directly to the energy demand for cooling in warmer climates requiring active cooling at certain times, although there is some additional flexibility in case dehumidification is required (Passive House requirements, n.d.).

Secondly, the next requirement aims to eradicate any other kind of pathway that might allow heat to escape, thus ensuring indoor comfort. An air renewal rate (n_{50}), with a maximum value set at 0.6 renovations per hour, is defined by the standard to guarantee the airtightness of the building's envelope, at a pressure difference of 50 Pa. This underscores the need for ventilation systems with heat recovery capabilities, allowing the outgoing air to transfer heat to the fresh air entering the space (Dequaire, 2012).

Finally, as mentioned above, the third requirement is responsible for limiting the energy consumed by the sum of the other services within the project, such as lighting, hot water, and appliances. This restriction on primary energy consumption must not exceed 120 kWh/m2 annually. Understanding the concept of primary energy within the Passivhaus standard involves recognizing its considerations of the environmental impact of various energy sources, considering losses suffered during transportation or conversion before project completion (Dequaire, 2012).

Apart from these essential three, some additional non-mandatory requirements are added by the Passivhaus Institut, cataloged by Wassouf (2015) as “indirect criteria” (p.71). According to the same source, some of the most important ones are overheating control and hygiene considerations. The first one, which has an important impact in warm climates, is mainly related to the recommendation of not exceeding a temperature of 25ºC in the interior air of the rooms for more than 10% of the time of annual use. The second addresses humidity, intending to avoid surface condensation on windows and mold formation on the inner face of the building envelope. Besides these two, more such criteria generally focus on user comfort.

In summary, all the requirements above highlight the significance of the Passivhaus standard in enhancing building energy efficiency, while maintaining user comfort as a priority. Nonetheless, meeting these requirements alone is insufficient for certification, as several additional principles influence the certification process too.

2.2.2. Passivhaus Design Principles

When deciding to design a building under the Passivhaus standard, it is necessary to know that the process cannot only be guided by the mandatory energy efficiency requirements for certification. When working at these demand levels concerning energy consumption, attention to detail during all phases of the project and considering the design principles established by the standard is essential.

Of course, the bioclimatic design approach is the first aspect that will provide a good basis for creating a highly efficient building. Apart from the great importance of the project’s location, several aspects require special attention. Among others, orientation and shading systems are essential elements to ensure optimal use of sunlight. Likewise, features such as the relationship between the envelope area and the volume, or the selection of natural materials in the construction, are also fundamental to achieving a good design (Zurro García et al., 2023). The first of the two previous aspects indicates the greater or lesser performance that the building will have since it refers to the compatibility of the building. According to Moreno-Rangel (2020), the lower the A/V ratio, the lower the thermal transmittance, or, in other words, the more compact the building is, the lower the energy demand.

In any case, the Passivhaus standard sets out five design principles that every project should follow to achieve a satisfactory result and meet the basic requirements for certification. These principles to be followed are the importance of thermal insulation, the need for high-performance windows and doors, the absence of thermal bridges, the guarantee of airtightness in the envelope, and the use of mechanical ventilation with heat recovery (MVHR) (Passive House requirements, n.d.). These guidelines, together with energy-efficient appliances and lighting, are key to minimizing energy demand and optimizing the performance of the building's envelope (Moreno-Rangel, Passivhaus, 2020).

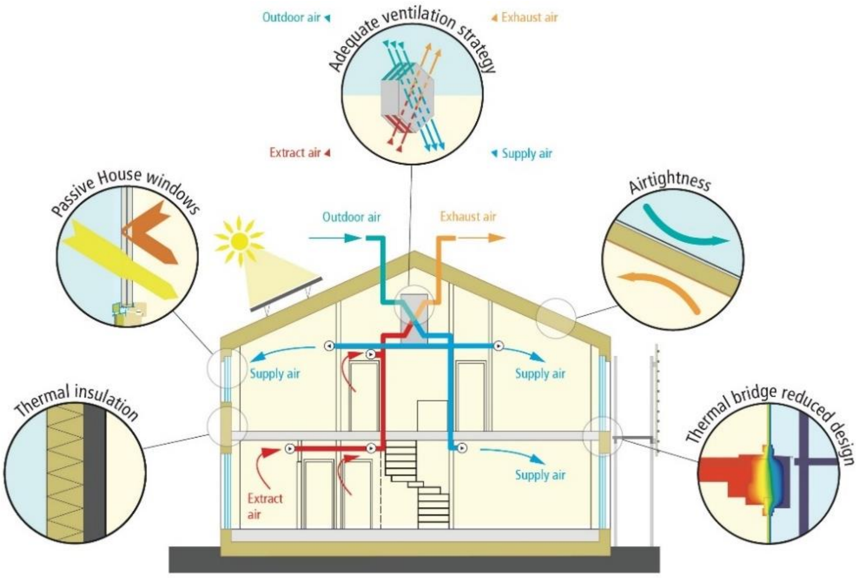


Figure 4. Key Passivhaus design principles (Source: Passive House requirements, 2021).

Firstly, as previously mentioned, having a good insulation system in the building envelope is critical. The composition of the building’s envelope determines its thermal resistance and, therefore, its capacity to cope with the exterior-interior temperature difference. The greater the resistance, the lower the loss of heat or cold and, consequently, the lower the energy demand in indoor air conditioning (Zurro García et al., 2023). Among these layers that form the envelope, the choice of the insulation and its position to the rest is crucial.

Secondly, as any element being part of the building envelope, windows and doors in contact with the exterior require special attention. These singular points have a fundamental role in controlling the overheating or thermal gains depending on the outside temperature, while also impacting the insulation and airtightness of the envelope (Moreno-Rangel, Passive House Institute and US Green Building Council, 2022). Apart from the windows’ characteristics and their efficiency, the design and layout of the openings also greatly influence the optimization of the thermal resistance of the envelope.

Continuing along the line of singular points of the envelope, it is necessary to ensure the absence of thermal bridges for obvious reasons. Thermal bridges are points of reduction of the envelope efficiency since they form areas where heat and cold transfer are facilitated. This is one of the reasons that causes the greatest number of problems in terms of efficiency, condensation, and humidity (Moreno-Rangel, Passive House Institute and US Green Building Council, 2022). The easiest way to prevent thermal bridges is to pay attention to the constructive solutions from the moment they are designed.

In addition, it is necessary to ensure the airtightness of the envelope to achieve the desired energy efficiency. This aspect is of great importance since air infiltration can reduce the building's energy efficiency, and it is also regulated in a very demanding way by one of the mandatory criteria for certification. There are two layers of an air barrier that are mandatory for any Passivhaus project, one is used to cover the joints that appear by the constructive process, and the other, usually on the outside, protects the building from cold air (Moreno-Rangel, Passive House Institute and US Green Building Council, 2022). The Passivhaus Institut considers it essential to check airtightness through the BlowerDoor test (Airtightness measurements, n.d.), a pressurization procedure carried out with the help of a fan that serves to determine different parameters related to airtightness (Barreira et al., 2017; Lerma et al. 2018).

Finally, the choice of a mechanical ventilation system with heat recovery (MVHR) allows Passivhaus buildings to ensure indoor comfort while minimizing energy losses in the conditioning of the building. It is worth mentioning that other ventilation methods can be used as long as they do not affect the mandatory criteria set by the Passivhaus Institut (Moreno-Rangel, Passive House Institute and US Green Building Council, 2022).

All these principles and the additional recommendations based on experience, are responsible for achieving projects capable of reaching very satisfactory energy efficiency thresholds. Therefore, it is advisable to keep them in mind from the first moments of the design process and to verify all the aspects of the building by using the tools offered by the certifying agency itself, which are explained in the following section.

2.2.3. Passivhaus Standard for Different Climate Zones

Owing to its solution flexibility and its direct dependence on the performance of each building, one of the key strengths of the Passivhaus Standard is the potential to be adapted to different parts of the world. The Passivhaus approach is meant to be valid in any climate, but naturally, depending on the specific characteristics of the climate, the goals vary. Likewise, some Passivhaus Institut requirements for certification can also be relatively flexible in justified cases where the climate demands so. Hence, the lack of implementation of this practice in a particular region at a time when it is expanding by leaps and bounds does not necessarily mean an impossibility of adaptation, but rather an interesting area for further research.

The Passivhaus Institut itself classifies the world into seven climate zones to make more specific recommendations regarding the most suitable solutions and its various certified components are also climate-specific (Schnieders et al., 2020). Some expected properties of the components depending on the project location can be found as recommendations, such as the expected transmittance values of the envelope, the efficiency of the equipment utilized, or the type of glazing required. The seven climate zones are shown below in Figure 5 and from coldest to warmest these are: arctic, cold, cold temperate, warm temperate, warm, hot, and very hot.

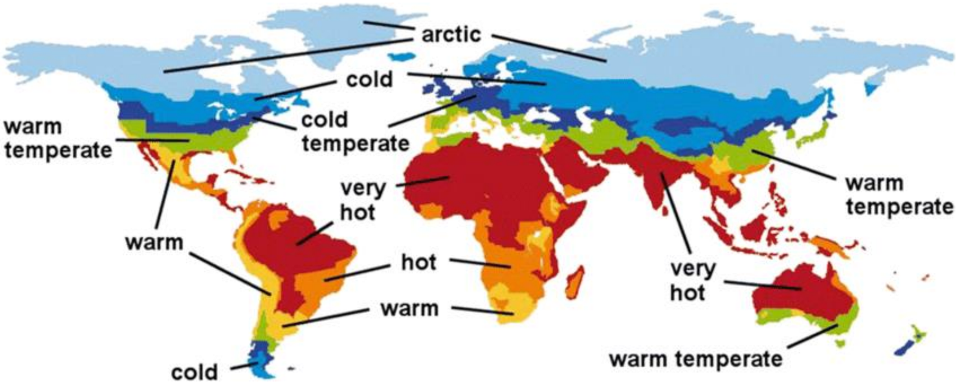


Figure 5. World map of Passive House climate zones (Source: Pallantzas, 2020).

Certainly, the distinctions between the nature of these climates imply that the strategies to be adopted by the designer to achieve the demanded energy performance are focused on significantly different objectives. Whilst in cooler areas it is essential to maximize solar gains and prevent heat losses, in the warmest ones a limitation of these same gains is required through the provision of a greater amount of insulation. Therefore, for temperate areas halfway in between the two previously mentioned cases, the main challenge is the most notable difference between their high and low-temperature seasons and the difficulty of achieving a solution responding to both. In any case, regardless of the scenario, the designer must always be aware of the prevailing conditions of the project and be the one to decide on the optimal solutions using the tools provided by the Passivhaus Institut, among which the PHPP is the main one.

2.2.4. PHPP Tool and Certification Process

For a project to be certified as Passivhaus, it is necessary to go through a process that begins in the design phase and ends when the building is ready. Ideally, when deciding to start a project of these characteristics, it is undoubtedly necessary to determine the appropriate training each party involved should have. Not only is it advisable for the architect or designer to know the standard, but also for any figure who will play an important role throughout the design and construction process to avoid possible setbacks.

The Passivhaus Institut first published the Passive House Planning Package (PHPP) in 1998, an energy modeling tool used to generate and evaluate energy modeling of buildings under stationary conditions as a prediction (Mitchell, 2020). Since its initial release, it has been improved and new functions have been added as it has been tested in practice, research into the standard has continued, with the tenth version being the most recent (Passive House Planning Package (PHPP)). This tool is fundamental in creating and certifying a building that follows the standard, as it verifies all the values necessary to check that the requirements set by the standard are met. In addition, as the standard does not set standard solutions beyond the design principles, this tool allows checking of the validity of the decisions made by the designer in construction solutions, materials used in these, and other technical aspects (Zhao, 2023). PHPP is an Excel file divided into different sheets, one for each data needing to be checked, using proven calculation methods (Sadeghi-Mohaved, 2018).

Throughout the design process, the building must be modeled with the PHPP tool being advisable to have training in its use and the support of a Certified Passive House Consultant (CPHC) (Brew, 2011). Thus, correct decision-making is guaranteed from the beginning, achieving the optimal answers to the challenges that arise when following such a demanding standard. After completion of the design process, it is crucial to be meticulous when building, as any change in the materialization process of the project means changes in the performance of the building and, therefore, must be verified with the Passivhaus Institut's tool. The official certification process will start when all the final values have been verified, being necessary to submit to the Passivhaus Institut the results of the PHPP and any additional information requested (Somuncu & Menguc, 2016).

2.3. The Passivhaus Standard in the US

Concerns about the impact of buildings’ energy expenditure on global warming are not a novelty and have been a field of study globally for decades. Among the countries that have been looking for solutions for quite some time is the United States, which began its journey toward reducing energy demand with studies at the Massachusetts Institute of Technology. In 1938, just before World War II began, a fund was established at this prestigious university to finance research focused on the active use of solar energy to provide buildings with the power demanded (Barber, 2008). Although the results of these early studies were interesting at the time, the energy crisis of the 1970s prompted a change in the direction of passive solar energy use in the country's housing stock. At that time, discussions began about strategies for passive house design, culminating in the concept of "super-insulated homes" because of the inconvenience caused by overheating in the early solutions during the hottest periods of the year (Parker, 2009). The main objective of this type of construction was to reduce the annual energy demand of buildings through the use of a greater amount of insulation, as well as the search for airtightness so that the thermal resistance of the building’s envelope could be increased to the maximum (Cooperman et al., 2011). In many ways, the concept was groundbreaking changing how passive architecture was approached, setting precedents for the ideas that would come after it and many of the standards that would be created in the course of research into energy conservation in buildings. In fact, according to historical information provided by Passivhaus Institut sources, this concept and the houses built following it were very close to the reasoning behind the creation of the Passivhaus Standard and are considered fundamental for understanding its main idea (The Passive House – historical review, n.d.).

Throughout the last decades of the twentieth century, a significant increase in energy efficiency regulations and standards appeared to answer the need for a substantial change in how buildings were designed in the United States. In 2002, the German architect Katrin Klingenberg decided to introduce the Passivhaus Standard in the country, after seeing its positive impact in German developments. The European-based Standard materialized the following year in the United States with the construction by Klingenberg of the Smith House in Urbana (Illinois), which would be the first certified house in North America (Kernagis, 2008). A study on the performance of this dwelling after its construction could demonstrate how the Standard was both suitable and a potential solution to reduce the high energy demands of buildings in the United States of America, without neglecting their comfort. Compared to other houses of the same characteristics, built without following the principles set by the Passivhaus Standard, this construction could reduce up to 90% of the energy consumption of the building. Once it was demonstrated that this difference was feasible for houses in the country, work had to begin to spread this practice, and so in 2008, the Passive House Institute U.S. (PHIUS) was founded (Hogan, 2011).

Since then, the Standard has been implemented in the North American country, where every year it has gained popularity with more professionals approaching the concept and adapting it in different states. Nowadays it is a practice that has gained relative popularity, especially in the last decade with the affiliation of at least three organizations to the International Passive House Association. This incipient recognition is responsible for the fact that every year buildings continue to be certified in the country, which by mid-2024 has 80 officially certified buildings and another 69 in the process of being certified (Passive House Database, n.d.). According to the Passive House Database (n.d.), the two leading states in Passivhaus construction are as of now (August 2024) New York with 41 buildings, and California with 22. If further counting based on the data provided by this source of information, it is remarkable how most of the projects designed under this Standard are located in the northern part of the country, being absent in the states of the southern half of the country, except for the previously mentioned California and the state of New Mexico. The reason for this could be related to the fact that the climate in this part of the country makes it difficult to approach the values demanded in the certification, since it has hot and humid summers as a common feature, besides being formed by states that often suffer from severe weather events. However, part of a doctoral thesis conducted at the University of Illinois at Urbana-Champaign by Abendroth (2013) states as a conclusion of his studies that with the advancement of building solutions, the possibility of building according to Passivhaus certification parameters in different climates of the United States would be a plausible reality even in regions where it is more complicated to achieve this strict Standard.

Therefore, it can be deduced from the above that it is only a matter of time before the Passivhaus standard is brought to all parts of the country, a possibility that depends mainly on the new construction techniques and the adaptation to local climate circumstances. Especially in the southern part of the United States, its integration would be beneficial to curb the high energy consumption of housing, which inevitably affects the alarming situation the world is facing today.

3. AN OVERVIEW OF OKLAHOMA

3.1. Presentation of the Context

The state of Oklahoma (United States) is located in the interior part of the country, included in the West-South-Central division. Within this division are also found Texas, Arkansas, and Louisiana, with Oklahoma closely related to these in cultural, historical, and climatological terms. Covering an estimated 68,596.53 square miles, it is the nineteenth largest state in terms of area of the fifty states forming the United States (QuickFacts, 2023). It had an estimated population of 4,053,824 citizens in 2023, generally concentrated in the state's largest cities. Among these, the most populous is Oklahoma City, the current capital, with 702,767 inhabitants. Following the capital, the cities of Tulsa (411,894), Norman (130,046), and Broken Arrow (130,046) are the most populated, with the rest of the towns in the state staying under 100,000 registered residents (QuickFacts, 2023).

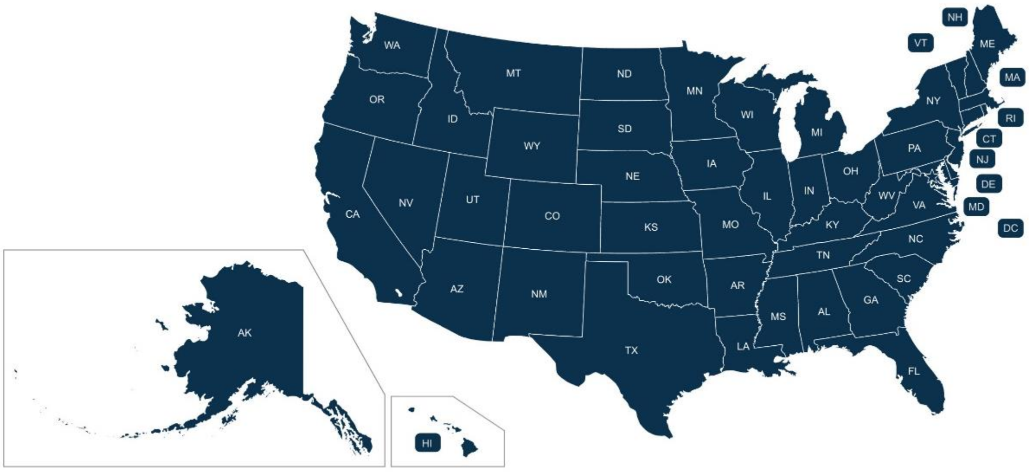


Figure 6. State By State Map (Source: State by State Map, 2019).

Regarding its borders, Oklahoma is geographically surrounded on all four sides by the neighboring states of Texas, Kansas, Missouri, Arkansas, Colorado, and New Mexico. Culturally speaking, the state has been attributed to the geographic characteristics of the Great Plains, although these are only found in the westernmost part of the state. This is mainly because prairies and plains characterize most of the state's surface, although there are some mountainous systems in the eastern part of the state. The state is bathed by three rivers of relative importance, as well as a generous number of man-made lakes. All in all, the geographical features turned Oklahoma into a land with potential for agriculture, which largely explains the development of its history and the culture that originated around its plains (Patton & Marston, 2010).

Figure 7. Landforms of Oklahoma (Source: Gibson, 1981, p. 6).

Oklahoma's cultural richness comes from a diverse, but also tumultuous and controversial history. Many centuries before the arrival of European settlers to the now Oklahoman territory, various tribes of American Indians inhabited this land guided by their customs and living habits (Fixico, 2018). The Spanish began to show interest in the fertile lands that today constitute the state in the 16th century, followed by the French a century later, turning this territory into the point that marked the point that separated the colonies of the two in the northern part of the American continent. With a long succession of events ahead that were to constitute the long stay of Europeans on the continent, these lands became a fundamental logistical point in the "New World" (Everett, European Exploration, 2019). During the early 19th century, the already-founded country of the United States of America began the process of recovering what was considered to be its lands, among which were those that formed the state of Oklahoma. Specifically, these lands became part of the recently proclaimed nation as part of the Louisiana Purchase in 1803 and it was not long after it was decided that they were the ideal place to relocate the Indian tribes due to their marginal and rural nature (Baird, 2010). Consequently, the first half of the century significantly impacted the history of Oklahoma, and even more profoundly that of American Indians through the officialization of forced relocating processes from their ancestral lands, exemplified by the Indian Removal Act of 1830 (Frank, 2010). During the 1830s through the 1880s, Oklahoma remained a designated "Indian Territory" resettlement area for Native Americans, a period that ended with the integration of Indian Territory into the United States through the granting of land and eventually statehood in 1907. This year, what we know today as Oklahoma was founded, with the unification of one state of the Oklahoma Territory and the Indian nations, which at this point lost any chance of dominating their lands (Everett, Indian Territory, 2010).

Beginning in the early 20th century, Oklahoma underwent significant oil discoveries, which quickly transformed it into a leading oil-producing region and encouraged a distinctive oilfield culture. Characterized by a highly mobile and seasonal workforce, a high demand for labor, and social and linguistic hierarchies, this culture shaped the stereotypical oil boom towns common within the state as well as part of its modern history (Weaver, 2010). However, in the 1930s Oklahoma endured severe economic, social, and environmental changes with the advent of the Great Depression and the Dust Bowl. Considered the greatest drought on record in the Great Plains and one of the largest-scale environmental disasters in U.S. history, the Dust Bowl brought massive dust storms that devastated the lands of Oklahoma and some other neighboring states (Wilhite, 2010). Together with the economic depression affecting the entire country, this event marked an unprecedented decline in agriculture, demographics, and the socio-economic conditions in the state, culminating in a rural-to-urban migration of a part of its population and a profound transformation of its industry (Mullins, 2010). Despite Franklin D. Roosevelt's New Deal attempts to reinvigorate the U.S. economy, Oklahoma saw limited gains due to political reluctance and the state's conservative stand, resulting in minimal long-term impact of these measures in the state (Bryant, 2010). After enduring all these difficulties, Oklahoma's involvement in World War II signaled a significant turnaround, catapulting the state's recovery and modernization. Fueled by defense spending and military infrastructure development, the economy was reshaped leading to urban development and industrial expansion that set the stage for post-war prosperity and demographic shifts (Agnew, 2010). The second half of the 20th century marked substantial growth in the state's economy, although the state's per capita income often lagged behind the national average (Warner, 2024).

At present, Oklahoma continues to face a complex socio-economic scenario, characterized by both challenges that need to be addressed and opportunities for growth and new developments to be incorporated. All in all, today it could be considered a state in transition compared to how other parts of the country operate, and it is actively working to balance its traditional industries with new challenges, all while managing the social and political complexities of a diverse population.

3.2. Climate Comprehensive Review

The state of Oklahoma experiences, due to its geographic and topographic diversity, a relatively varied climate that depends on the region and its characteristics. The climate throughout the state ranges from humid subtropical in the most eastern parts to semi-arid in the westernmost areas, according to the Köppen climate classification (Climate of Oklahoma, 2024). However, suppose an even more concrete classification of the different climates existing in this territory is sought. In that case, we can refer to the division made by the NOAA Physical Sciences Laboratory into nine climatic divisions, which are as seen in the figure below: Panhandle, North Central, Northeast, West Central, Central, East Central, Southwest, South Central, and Southeast (Location of US Climate Divisions, n.d.).

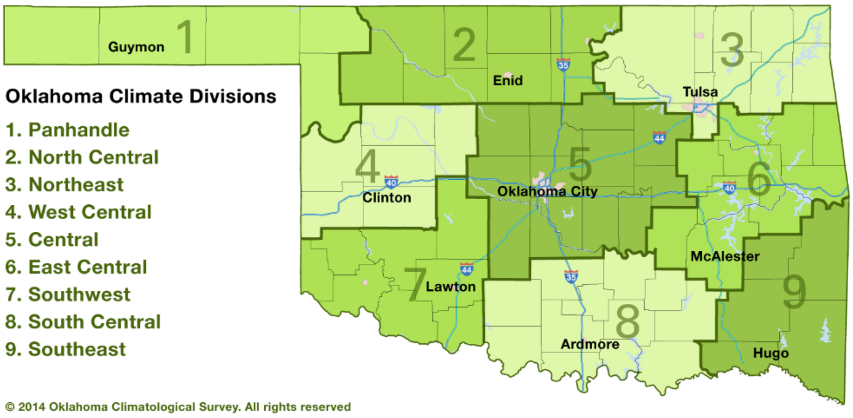


Figure 8. Oklahoma Climate Divisions (Source: Climate of Oklahoma, 2014).

Within Oklahoma, warm and humid air from the Gulf of Mexico substantially influences weather conditions, particularly affecting the southern and eastern portions of the state. These regions are marked by higher humidity, cloudiness, and precipitation when compared to the drier areas found in the north and west. In general, the state is characterized by long, hot summers, while winters tend to be mild and shorter with infrequent episodes of extreme cold. All in all, Oklahoma's climate can be considered a fairly temperate climate in terms of temperatures, although it should be noted that this does not mean that high maximums during the summer season are not reached (Climate of Oklahoma, 2024). The state experiences its highest probability of precipitation in the spring, also characterized by significant thunderstorms and tornadoes. In addition, flooding from rainfall and the rising of rivers and lakes presents additional hazards, especially during the wetter seasons. In addition to annually variable rainfall, Oklahoma has also faced severe periods of drought that have posed serious problems throughout history (Johnson, 2010). Located in the heart of what is known as “tornado alley,” Oklahoma's climatology can be classified as variable, severe, and unpredictable (Kelley, 2010).

As for the Passivhaus Standard climate classification mentioned in previous sections, Oklahoma falls into the warm-temperate zone that runs through an entire swath of the United States. Despite this classification, which may not be particularly appealing at first glance, any location in this state could present a great challenge for applying the Passivhaus Standard as it relates to its weather conditions. In conjunction with its developing status towards more efficient policies, its wide temperature range and seasonal variability make it an area of great interest. Furthermore, due to the research being carried out in the area regarding its climate, sufficient data is available to proceed with the design and certification of a house according to the standard. For this purpose, a considerable amount of data about the climatology of the project site is required to use the PHPP tool. This Excel file, designed by the Passivhaus Institut and provided to the designer, contains by default climatic data for numerous regions of the world including the state of Oklahoma. In this paper, the reference point for data collection will be the capital city of Oklahoma City, which is located within the central climate division. This has been decided since it is the most populated area and therefore has the greatest demand for housing, in addition to being the area for which the greatest amount of data is available.

To conduct a detailed analysis of specific climate conditions, the Passive House Planning Package (PHPP) is used, needing access to localized data. This data should include latitude, longitude, altitude, and daily temperature fluctuations during the summer months. In addition to these parameters, the tool also requires average monthly data about several key aspects such as outdoor temperature, radiation from the four cardinal directions, horizontal radiation, dew point, sky temperature, and ground temperature. These comprehensive datasets are crucial for accurate climate modeling and analysis, being necessary to enter them manually if they are not found in the PHPP database. This Excel spreadsheet does have the required information on Oklahoma City and further data gathering, and a graphic provided by it is attached below to give a general notion of the state's climatology.

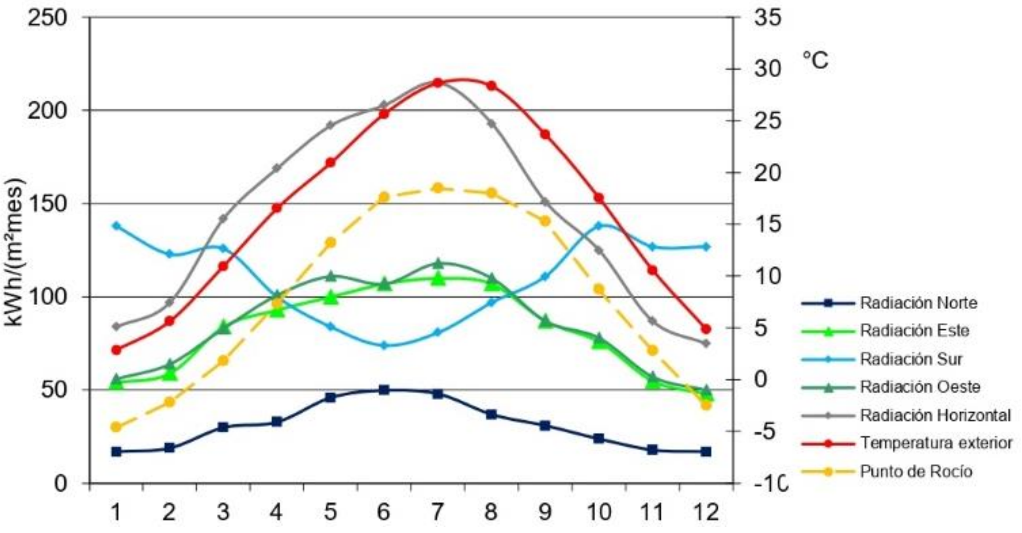


Figure 9. Graph with Oklahoma climatological data provided by Meteonorm (Source: PHPP_V9.6a).

3.3. Analysis of Housing in Oklahoma

The residential architectural landscape in Oklahoma has undergone many transitions, shaped by its complex history. Initially dominated by indigenous structures, the architectural scene radically changed with the removal of Native tribes and the incorporation of Appalachian influences as the region transitioned to statehood. During this time of transition, housing evolved into more complex constructions culminating in a rich diversification of styles by an emerging middle class seeking Victorian, Spanish Colonial, and Craftsman styles for their homes. The Great Depression introduced the New Deal program influences that reshaped the construction landscape, and the post-World War II economic boom meant the arrival of modernism and the spread of suburban developments (Henderson, 2010). This history facilitates comprehension of the process experienced by residential architecture in the state, constantly facing challenges and changes.

For the purpose of adapting the Passivhaus Standard to the state of Oklahoma, it was decided to create a model home that responds to the current reality of the residential landscape, for which a deeper analysis of the predominant housing typology here has been carried out. Similar to the decision made on the climate research in this paper, the data on housing in the state will be based on Oklahoma City, since it is the most populated area and the one for which the most information is available. According to the latest data published by the American Housing Survey (2021), the most common type of residential building in Oklahoma City is the single-family detached house, which makes up more than 75% of the residential constructions. An understanding of the style of these houses typically found in the state requires an acknowledgment that the median year of construction of this type of building in the city is in the early 1980s (American Housing Survey (AHS), 2021). With this perspective, it can be understood that the predominant styles in single-family housing correspond to the post-World War II Modern movement in Oklahoma.

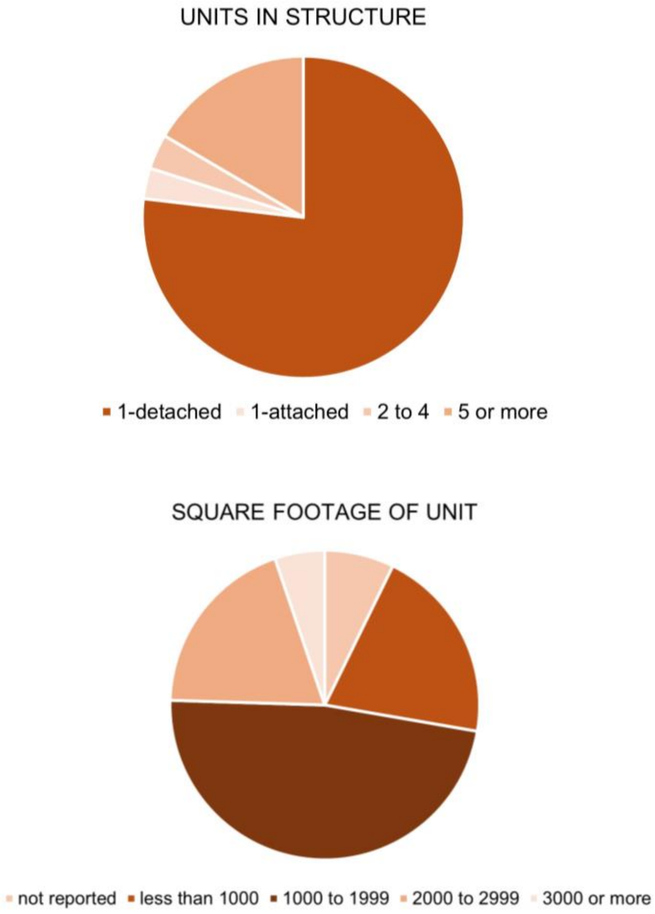


Figure 10. Trends pie charts on the most common housing features in Oklahoma City by 2021. Own elabora-tion with AHS data.

Specifically, among the various styles, the Ranch style and its subtypes can be considered the most common among homes in the region over the past decades, found mostly in residential suburbs in all its forms and versions. This style of housing resulted from the demand for larger homes in the prosperous times following the end of World War II in the middle of the last century when family size and production in the housing sector experienced a substantial increase (Ozan, 2014).

Figure 11. Ranch-style house (Source: Ozan, 2014, p. 46).

The ranch-style home was first born in the California suburbs in the 1930s, offering a relatively affordable housing option with an attached garage and intended for the spacious lots these neighborhoods offered (Bays, 2017). This architectural style is characterized by the emphasis on its broad façade and the integration of the garage on one side of the 1-storey structure (Emery, 2016). In addition, low-pitched hipped roofs, wide eaves, and the disappearance of the front porch are also among its design features (Bays, 2017). The exterior finishes could be very varied, usually combined to give a more interesting appearance. Today, if walking the streets of average Oklahoman neighborhoods, one still sees the clear influence of this style even in new construction. Looking at various reconnaissance surveys conducted over the last ten years in neighborhoods like Indian Hill in Enid (Emery, 2016) or counties like Payne County (Bays, 2017), the popularity of this style is evident.

Furthermore, this style of home summarizes the most common traits among single-family detached homes in the Oklahoma City study area, according to the latest Census Bureau report. By tracking the characteristics with the highest percentages according to the data provided by the U.S. government, we can describe the current most popular house type in this metropolitan area. Single-story homes account for more than 60% of the total, with 45% of the cases having between 1,000 and 2,000 square feet and 50% of them having 3 bedrooms. In addition, these data also reflect another important aspect to consider as almost 80% of the single-family buildings have a concrete slab foundation, another shared feature with ranch-style homes (Ozan, 2014).

Therefore, based on all the above information, it is possible to get a general idea of the type and style of housing that dominates the residential landscape in the most populated area of the state. The characteristics gathered in this section will serve as a guide to designing the model house that will be the object of this work, and to which will be attributed the constructive qualities necessary to achieve Passivhaus certification in the local climate.

4. SOLUTION PROPOSAL

4.1. Model House Bioclimatic Design

The model house has been designed in this paper to adapt the Passivhaus Standard in Oklahoma to the closest possible reality, using as a baseline a common house found in any of its neighborhoods at present. The goal is not only to adapt this building to the climate and to achieve the most energy-efficient response based on the Standard but also to do so with the resources and knowledge already existing in this region. Thus, the house has been designed following the style and common characteristics of single-family homes in Oklahoma City, obtained from the research in previous sections. The result is a single-story house with three bedrooms and a total built area of 140 square meters (approx. 1500 square feet), excluding the area corresponding to the garage. Along the Ranch style lines, the design features this garage attached to the structure on one side, a wide façade, and a hipped roof with perimeter overhang.

The decision for the orientation of the model home was made optimally responding to the local climate, this being an important step towards the creation of a bioclimatic design that facilitates an optimal path toward Passivhaus certification. Consequently, the front façade and garage have been faced north, with the idea of placing the house's main rooms on the south side for greater comfort and a sense of privacy. In general, the backyard is a fundamental part of this style of housing, and for this reason, it is also usually the user's preference that the life inside the house responds to it. Therefore, rooms like common areas and bedrooms have been placed to meet those requirements, but also to suit the climate and to follow the Standard’s recommendation of facing the majority of windows towards the equator.

Figure 12. Model house floor plan. Own elaboration.

In the interest of achieving the ideal layout of the different rooms, both the optimal response to the climate and the functionality of the spaces have been important. Therefore, it was concluded that the server elements should be placed on the north side of the building, allowing the garage to be connected to the house through them and both elements to serve as a “barrier” to prevent the effect of the cold Oklahoma winter wind. The house has a kitchen, living area, a shared bathroom, two double bedrooms, and an en-suite master bedroom. By concentrating all the wet spaces in one area, the task of the installations also becomes easier, besides giving more freedom in the layout of the rest of the space. Hence, this has made it possible to organize the common living areas and bedrooms in such a way as to make the most of the sunlight, which is an indispensable factor in general well-being and comfort. Considering the aforementioned, the dining and living rooms have been placed in a large central open area, as shown in the floor plan in Figure 10. These will operate as the core of all the activity of the house, as well as being the direct connection with the main backyard through a large sliding window. On both sides of this central space, the main bedroom is placed on the west side and the other two on the east.

The final feature of the design to be discussed involves the strategic placement of the openings within the building’s envelope. In the context of Oklahoma, addressing the seasonal fluctuation is challenging, since responding optimally to this becomes harder because of the different extremes. To achieve the low heating demands specified by the Passivhaus Standard during the colder months, it is in our best interest to maximize solar gains through south-facing openings, while also safeguarding against the cold northerly winds prevalent during Oklahoma's winters. Consequently, windows have been strategically positioned both in the common areas and in the two bedrooms facing south. Conversely, minimum openings are featured in the north façade, with only one window serving the third bedroom and the main entrance, which is partially sheltered by the garage´s structure.

Figure 13. Model house south and north elevations. Own elaboration.

However, these design choices may have consequences when responding to the cooling requirements, potentially leading to overheating issues during the hot summers. To mitigate the adverse effects of solar exposure, the design facilitates cross ventilation through additional openings both in the east and west facades as an extra nighttime cooling strategy to consider. Equally important when designing a passive house are the shading elements, which also play a fundamental role in thermal comfort, such as the installation of Venetian blinds on all windows. Likewise, the overhanging roof protects from the high summer sun and the placement of windows close to the inner face of the envelope helps in enhancing shade. Furthermore, the installation of a prominent shading structure on the south side would be interesting to shield the glazed surfaces from direct sunlight. A back porch, for instance, could be the optimal fit for this particular model home as it resonates with the popular styles found in American homes, offering at the same time a seamless transition between the house and the backyard. This integrated option would ensure a better energy-efficient performance of the house throughout the year, responding to both the passive design principles and regional architecture features.

Figure 14. Model house east and west elevations. Own elaboration.

These prior decisions made during the design process require reflection and forward planning, as they directly affect the outcome and potential Passivhaus certification. The project must respond to the environment and climate from all perspectives to ensure the best possible energy efficiency performance.

4.2. Construction Techniques and Material Selection

For any architectural project, all design-related choices must necessarily be supported by a reflection on how the idea is materialized. As discussed in this paper, the Passivhaus Standard does not dictate a specific solution or construction process to achieve the required energy values for certification. Hence, the designer must decide which construction options are adequate for the project and its context. Naturally, proposing the optimal solution for the location and ensuring correct execution are fundamental tasks in the design process of a Passivhaus house. Precisely, for this reason, the main part of this work is focused on finding a base building solution suitable for Oklahoma to make feasible the development of single-family homes following these energy efficiency guidelines, as a result of the preliminary analysis and further research.

4.2.1. Conventional Building Methods and Material Selection in the Region

A first step, then, must be to know the construction methods used currently in the state and if these practices are compatible with the objectives to be achieved. Typically, the construction practices for different types of buildings are widespread throughout the United States, and such is the case for single-family dwellings. Thus, it is assumed in this paper that this typology of residential projects is built in a generalized manner within the country, Oklahoma included. Henceforth, part of this section will be focused on describing the generic single-family home in the United States, conventionally built using light wood framing construction techniques (Jellen & Memari, 2019). According to Jellen & Memari (2019), this is the most widely used solution in the country for several reasons, including the building industry's familiarity with this method, the availability of the required materials in most regions, and the ease of transportation and execution.

Figure 15. Wood frame house (Source: Langdon, 2022).

Besides the foundation, the main structure of this type of construction is made employing wooden studs of variable dimensions, generally assembled utilizing nails, screws, or other fastening methods. The commonly used material in the foundation of the generic single-family home is concrete, mostly in the form of slab-on-ground specifically in Oklahoma. Particularly this choice in the state is due to the soil conditions, and also to the fact that basement construction is not usual in the area. Thereafter, floors, walls, and ceilings are all constructed with wooden framing and reinforced with structural wood panels, such as oriented strand board or plywood, to ensure stability and safety (Jellen & Memari, 2019). Typically, the roof of the generic house is pitched, and it is carried out with different construction methods depending on its typology; in Oklahoma, it is common to see many hipped roofs. After the structure is completed, the construction process and the elements and materials used are more variable depending on the project. However, some features that the American generic house usually has are the positioning of insulation in the cavities between studs in both walls and attic and the placement of water-resistant barriers on the outside of the structure's sheathing. The materials used for these tasks, as well as for the exterior and interior finishing, are what normally differ within developments.

Such decisions are usually influenced by the adaptability to the climate and the user's preferences.

4.2.2. Project-Specific Construction Methods and Material Choices

Once the commonly used methods are known, the search for the most appropriate solutions for the model house’s context begins. These are intended to respond equally to the ambition of achieving Passivhaus energy values, the local climate, and the labor and materials available in the area. All these factors are considered to make the house not only sustainable in terms of energy but also in many other ways, including the use of local labor and materials.

In the case at hand, the model house will also be designed with a lightweight timber structure on a reinforced concrete foundation slab, but with some slight variations. A double-stud structure is proposed for the building, a practice that is becoming increasingly widespread in the country and does not differ excessively from the conventional one. This type of structure is proving to be successful when composing walls with low transmittance values, as it has a cavity between the two frames where more insulating material can be placed, generally dense-packed cellulose. Beginning with this base element, the exterior walls' different layers are placed both inwards and outwards and the hipped roof is erected over this structure, again using a light wooden framework consisting of I-joists. In later sections, there will be a more extensive breakdown of the total composition of these three types of enclosures (slab, walls, and roof), since they are the ones that will form the envelope of our model house, in which the garage is not included.

Regarding the building materials employed, timber predominates in everything that has to do with the building's structure. From this point, materials used in, for example, the insulating task are dense-pack cellulose in walls and roof, and XPS rigid foam exclusively for the foundation slab. One important consideration was for the interior and exterior finishes to also meet common Oklahoma state practices. On the one hand, the interiors are solved with drywall and engineered wood flooring, both being widespread practices in the United States of America. On the other hand, on the outside, walls are clad with fiber cement boards and the roof is finished with zinc sheeting, a common solution for housing in the state.

4.3. Detailed Design Components and Connections

The components that will be analyzed in further detail within the selected construction system are those forming part of the exterior envelope of the dwelling, as well as the singular points formed by assemblies or openings. These elements must respond to the expected performance individually and as a whole, avoiding the possible appearance of thermal bridges at singular points. As known from the introduction of the Standard in previous sections, the continuity of the envelope is essential both for its thermal resistance and to achieve the airtightness values required by this. Realistically, it could be the case that not all enclosures of the same type in a building have the same composition, but for simplification purposes, it is decided that they will have the same properties.

4.3.1. Floor System

The first envelope element to be analyzed is the floor system in contact with the soil, which as previously mentioned, has a reinforced concrete slab as a structural element. This slab of considerable thickness serves as the structure's foundation and all the layers that will constitute this system, classified into interior and exterior, are distributed based on this slab. In the following Figure 15, the complete composition of this element is graphically shown, with its different materials and thicknesses.

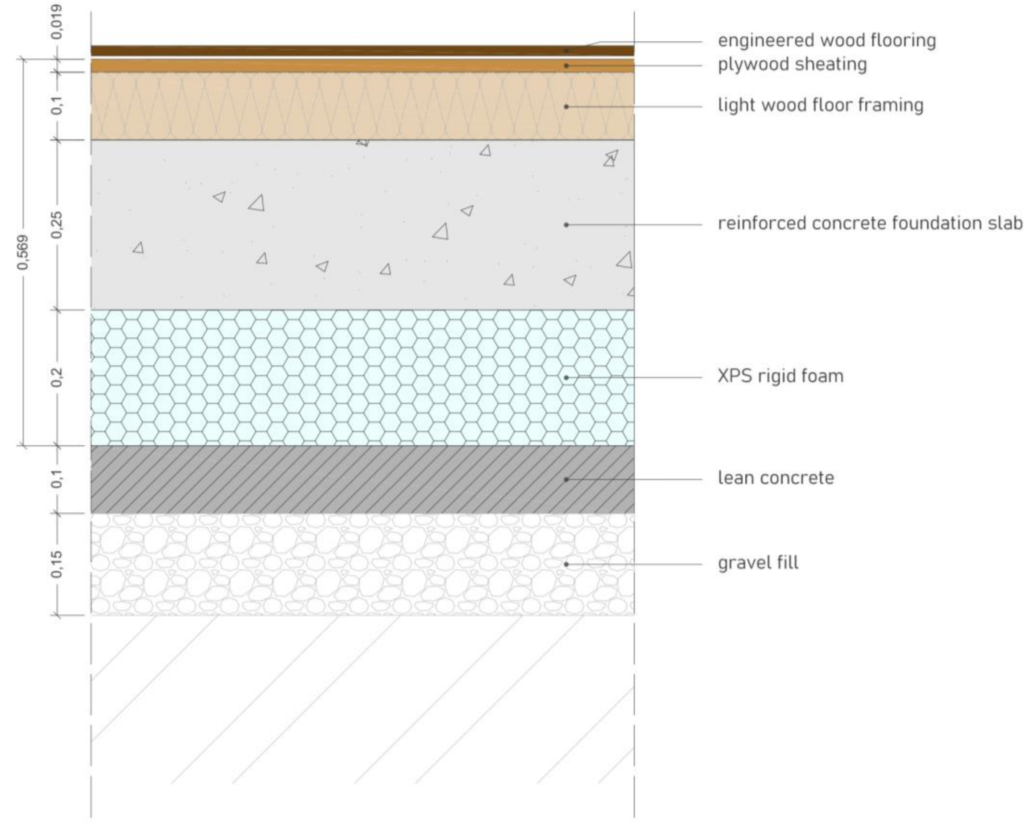


Figure 16. Floor system detail section. Dimensions in meters. Own elaboration.

Following the most usual practices of the Passivhaus Standard, insulation with rigid XPS boards is placed outside the system. Such material is suitable as it is a good insulator, highly resistant, and capable of withstanding the loads transmitted by the foundation. Its collocation follows two previous layers that prepare the ground with which it is in contact, a draining one formed by gravels and a well-leveled surface made of lean concrete. Once these two layers and the concrete slab are in place, a wooden framework is placed with a double function: structural and floor preparation. This lattice is filled with dense-pack cellulose to provide the system with additional insulation thickness and is completed with plywood boards. On top of this last layer, the preferred finishing for the interior floor can be installed, in this case, engineered wood flooring. The effect of the interior finishing on the effectiveness of this enclosure in terms of efficiency is negligible so a different solution could be chosen, without this meaning a worse performance.

The following table presents, in order, from inside to outside, the different layers mentioned and their respective thicknesses.

LAYER	THICKNESS	
	(mm)	(inches)
Engineered wood flooring	15	9/16
Wood flooring adhesive	3	1/8
Plywood sheating	19	3/4
Light wood floor framing filled with dense-pack cellulose	100	3 15/16
Reinforced concrete slab	250	9 13/16
XPS ridig foam	200	7 7/8
Lean concrete	100	3 15/16
Draining gravel fill	150	5 7/8

Table 1. Floor system layer information. Own elaboration.

4.3.2. Exterior Walls

In the case of the walls, the element that serves as a base is a double-stud structure, a dual timber framing that rests on the foundation and whose cavities are filled with insulation. Furthermore, there is a continuous cavity between these two frames allowing the placement of a larger amount of insulation to reach the required U-value. Although it is this thickness of the envelope the one that determines the thermal resistance of the element to the greatest extent, the solution includes other layers shown in Figure 16.

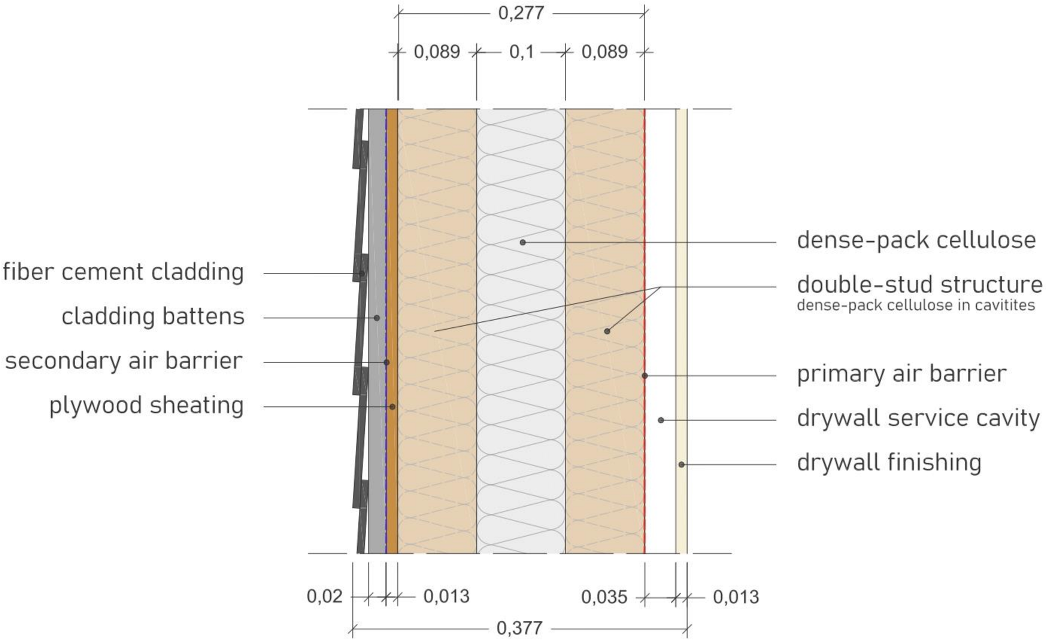


Figure 17. Exterior walls detail section. Dimensions in meters. Own elaboration.

One fundamental requirement when designing and building a house to be certified as Passivhaus is the airtightness of its envelope. To achieve the stringent values required by the standard, a first vapor barrier is placed on the inner face of the base structure, a vapor and air-tightness-regulating membrane. Naturally, the execution of this point of the envelope is crucial to ensure a satisfactory result and, from this stage, the interior wall finishes can be set in place. Meanwhile, on the exterior side, the structure is enclosed with plywood sheathing, which serves as a solid support for the secondary air barrier. This latter is composed of a waterproof membrane open to diffusion, on top of which the exterior cladding can be installed. The wall finishes are drywall on the inside and fiber cement cladding on the outside, both properly fastened to their respective metal battens. However, again, as in the solution proposed for the floor system, the finishes have a relative impact on the efficiency performance of the solution and others could be suggested if desired. Regardless, due to their common use in the area and to sustainability criteria, the materials that have been preferred can be seen again in the following table organized from the interior to the exterior of the wall.

LAYER	THICKNESS	
	(mm)	(inches)
Drywall interior finishing	12,7	1/2
Drywall service cavity	35	1 3/8
Primary air barrier: reinforced hydrosafe high-performance vapour check	0,4	1/64 (16 mils)
2x4 stud wall, 24 in. o.c.	88,9	3 1/2
Dense-pack cellulose	100	3 15/16
2x4 stud wall, 24 in. o.c.	88,9	3 1/2
Plywood sheating	12,7	1/2
Secondary air barrier: diffusion-open and weathering-protection membrane	0,7	1/32 (28 mils)
Cladding battens	20	13/16
Fiber cement cladding	8	5/16

Table 2. Exterior wall layer information. Own elaboration.

4.3.3. Roof System

Completing the envelope at the top of the building is the roof system, a critical element in a climate such as Oklahoma's. At a location where adverse weather events occur frequently, a resilient system is key to withstand them. For this reason, rather than opting for a conventional lightweight framing system, the use of an I-joist is chosen in this work because of its high strength and the ease of creating spaces with greater light between spans. Moreover, its narrower geometry allows a greater amount of insulation to be fitted between the rafters forming the roof.

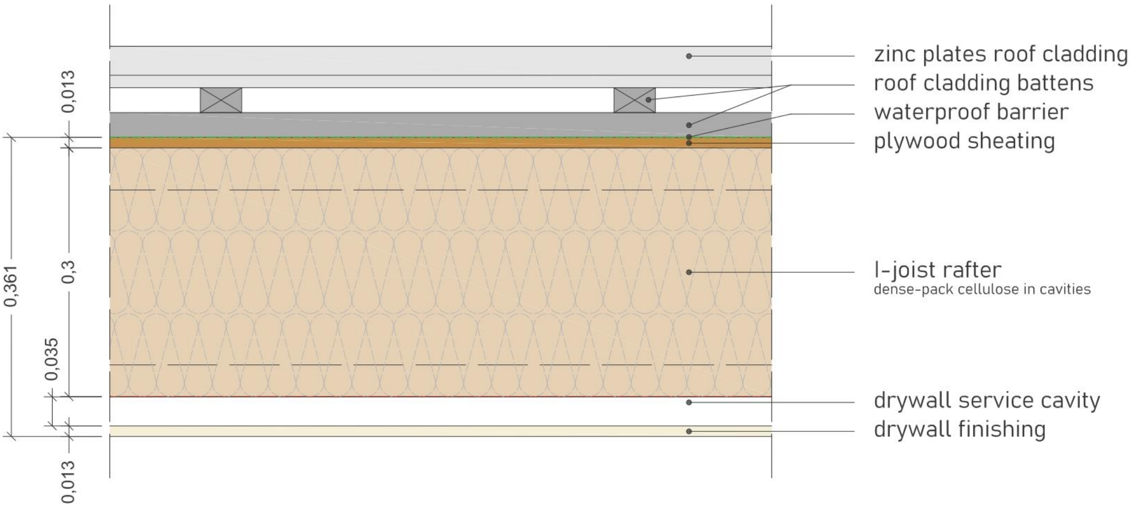


Figure 18. Roof system detail section. Dimensions in meters. Own elaboration.

Beginning with this structural element formed by the set of rafters, the necessary layers are placed, as in the previous cases, both inside and outside. On the inside, the same drywall finish proposed for the walls continues, although evidently, it is the exterior that differs. On top of the assembly, plywood sheathing is again used to cover the structure and enable the proper placement of the waterproofing layer on the roof. With this task completed, the selected finish of zinc sheeting can be installed. Along with being commonly found in Oklahoma single-family dwellings, it is considered a highly advisable choice due to its resistant and durable qualities. This is a low-maintenance type of roofing material designed to handle inclement weather and will help minimize solar gain during the warmer periods of the year given its reflectivity. Once more, the table below provides details additional information about the different layers that compose the roof system.

LAYER	THICKNESS	
	(mm)	(inches)
Drywall interior finishing	12,7	1/2
Drywall service cavity	35	1 3/8
I-joist rafters structure filled with dense-pack cellulose	300	11 13/16
Plywood sheating	12,7	1/2
Waterproof barrier	0,7	1/32 (28 mils)
Vertical metal battens	30	1 3/16
Horizontal metal battens	30	1 3/16
Zinc plates rood cladding	8	5/16

Table 3. Roof system layer information. Own elaboration.

4.3.4. Envelope Openings

All building envelope elements have a key role to play in energy-efficient performance, such as windows and exterior doors. Specifically, window components forming the glazed surfaces the house is to be equipped with are highly sensitive points, which must be designed in a very conscious manner. Besides inevitably implying a thermal bridge in the envelope to be reduced to the possible maximum, their strategic placement is crucial in a climate of these conditions.

Under these circumstances, the use of triple glazing with low emissivity is always highly recommended to reduce solar gains in summer and losses in winter, as well as a low transmittance value for better insulation capacity. Also, when in a warm temperate climate, one should look for glazing with a moderate solar factor to reduce to some extent the amount of solar energy capable of passing through the windows. External elements that protect these surfaces from the sun are naturally advisable in times of high sun incidence, in this case, Venetian blinds are suggested. For the model house, the decision was taken to install a glass with these specifications, whose values are set by the PHPP itself and are utilized for the calculations made in the PHPP. Therefore, the projected windows should have a glass with a transmittance (Ug-value) of 0.6 W/(m2k) and a solar factor (g-value) of 0.5.

Beyond the properties of the glass, the configuration and characteristics of the window frames are another highly important issue. Whenever possible, it is recommended to use components already certified by the Passivhaus Institut, which can be found in its Component Database Portal along with an official documentation containing all their specifications. The insulating capability of the frames will, naturally, have a significant impact on the thermal bridge formed between the frame and the wall, as well as its quality and sealing in terms of airtightness. On the latter factor, the positioning concerning the different layers of the wall, good construction practices, and the employment of adequate airtight seals ensuring the absence of air leaks, play an important role. Together with the rest of the building's envelope, these components should contribute to the formulation of a thermal and airtight continuous envelope.

Therefore, to offer a construction solution made as realistic as feasible, research on real components for doors and windows suitable for the treated climatic conditions and locally available has been carried out. Thus, using the database provided by the Passivhaus Institute, elements of the “smartwin” line have been found. These components, in addition to being certified with the highest possible rating (phA), are particularly suitable for cold and temperate climates, which makes them especially appropriate for this case study. The frame consists of a central timber structure, clad with aluminum and featuring very good insulating qualities. Further breakdown of the technical properties can be found in its certification document attached in the appendices of this paper. The same applies to exterior doors, whose values are also real and can be found in more detail in their corresponding certification form.

4.3.5. Connections and Envelope Continuity

The envelope continuity has such an important weight in the design of a Passivhaus house that it must be thought of as a single element from the start. Hence, constructive solutions for its various parts should be intended to optimally connect the building's insulation and airtightness members. Equally, the right execution on the construction site is a determining factor for achieving the desired result.

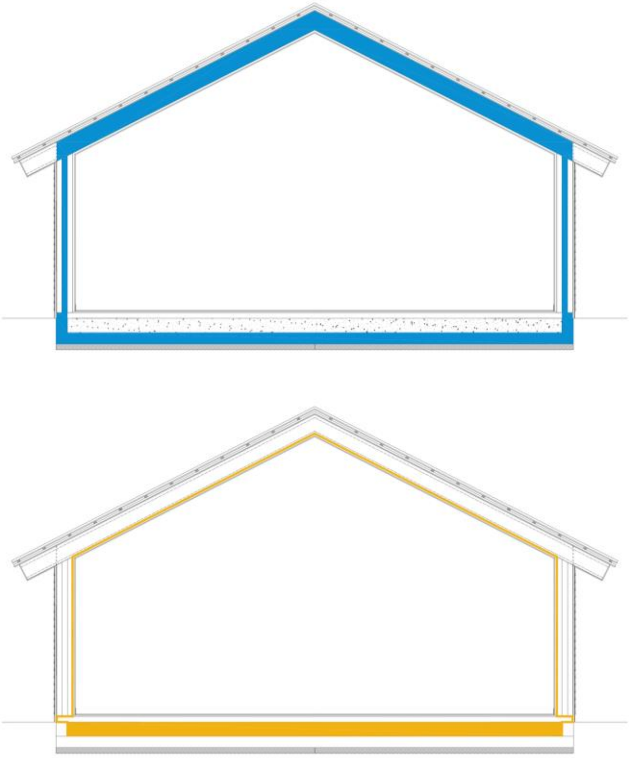


Figure 19. Continuous thermal and airtight envelope diagrams. Own elaboration.

On the one hand, in the practical scenario of the model house, the elements composing the continuous insulating layer are the XPS on the exterior side of the floor slab and the dense-pack cellulose placed in the intermediate cavity of the wall and between the rafters on the roof. On the other hand, the chosen solution for the continuity of the airtightness is carried out through membranes placed on the interior side of walls and roof, and the concrete properties of the slab itself. Regarding the latter, the junctions among the membranes and those between these and the concrete slab are particularly delicate points. Such unions are to be performed through overlaps and the use of appropriate airtight tapes or paints and can only be tested after being solved through a regulated BlowerDoor test. Figure 21 below illustrates how these encounters have been addressed in this particular case and the overall detail section as a whole.

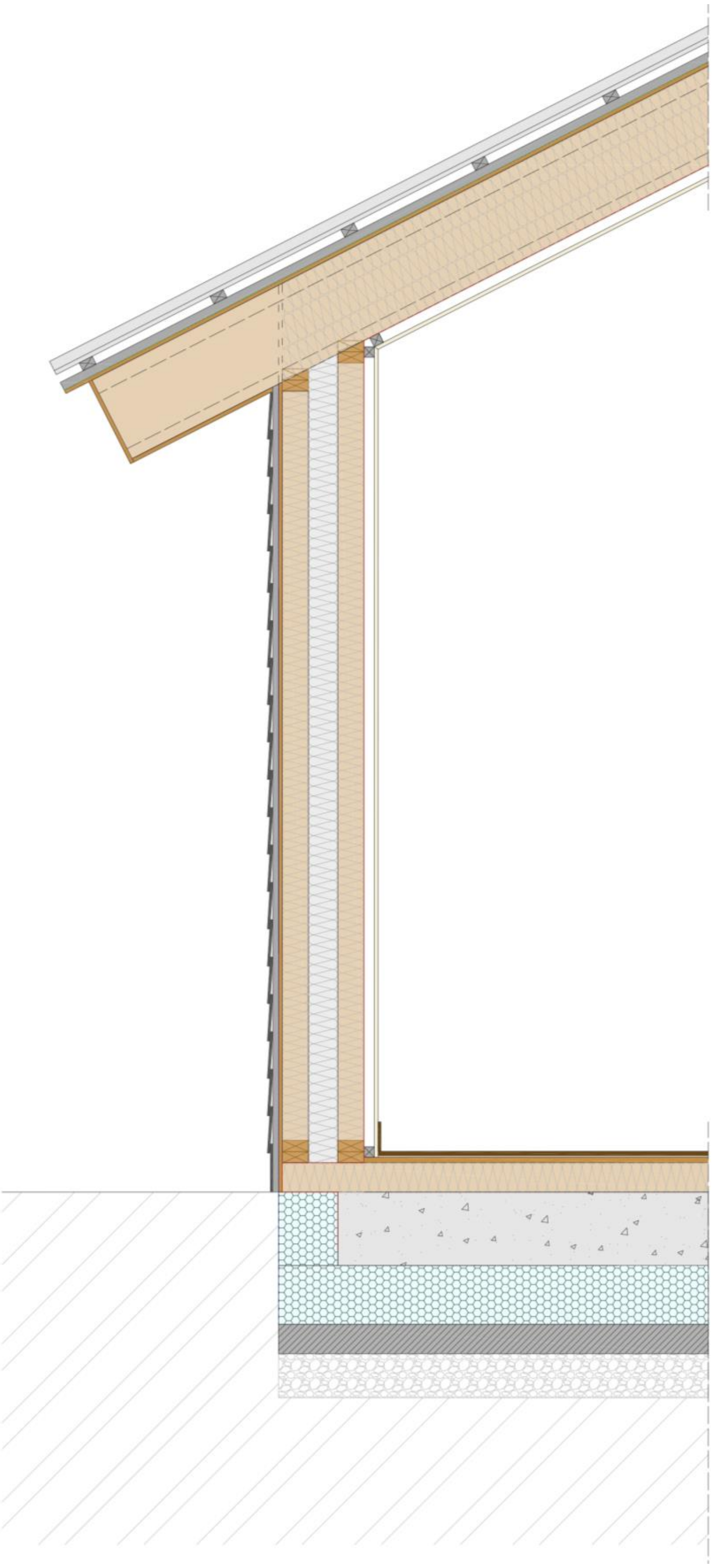


Figure 20. Overview of the constructive solution and the connection between its different components.

Own elaboration.

4.4. Thermal Envelope Analysis and U-Value Calculations

Under the assumption of correct completion of the envelope design during the construction process, the project is thermally evaluated using the PHPP tool. As mentioned previously, this instrument contains all the necessary data about the project location and its corresponding climate, thereby facilitating an accurate analysis to determine the suitability of a construction solution for the site. The PHPP is recommended to be used as a design support tool during the planning process to ensure a thermal envelope capable of delivering the desired results from the outset. Once the properties of the thermal envelope are known, its energy requirements can be analyzed, and the most appropriate solutions can be chosen.

The thermal analysis in the Passivhaus certification process begins with the calculation of the transmittance values of those elements that shape the building envelope in contact with the exterior. For this type of energy-efficient building, the goal is to have enclosures with the highest possible thermal resistance capable of optimizing the energy demand without compromising the comfort of its interior. Therefore, given that resistance (R-value) and thermal transmittance (U-value) are inversely proportional values, we look for envelopes with the lowest possible U-value. For this reason, the insulating properties of the different materials involved in the envelope are of utmost interest. All these values are calculated by the PHPP tool once the thickness (in mm) and the thermal conductivity (in W/(mk)) of each of the enclosure layers have been entered, therefore obtaining these data is a starting point. The table below lists in alphabetical order the conductivity values for some of the different materials used in the various parts of the model house. For simplification purposes in the simulation program, a few layers have been omitted due to their low impact on the final results given their thickness, e.g. the waterproofing membranes.

LAYER	THERMAL CONDUCTIVITY (λ)
	(W/(mk))
Dense-pack cellulose	0,038
Drywall	0,161
Engineered wood flooring	0,170
Fiber cement cladding	0,056
I-joist rafter	0,130
Plywood	0,115
Reinforced concrete	2,040
SPF lumber studs	0,120
XPS rigid foam	0,035
Zinc plates	110,000

Table 4. Thermal conductivity properties of selected materials. Own elaboration.

The U-value calculation process is relatively simple and is performed for each of the three elements constituting the envelope of our project. Although in our case it is carried out automatically by the PHPP once the values are entered, it is only necessary to know the three formulas which are used. First of all, the thermal resistance of each layer is determined by dividing its thickness by its thermal conductivity. Then we add up the resistances of all the layers forming the element, together with the internal (Rsi) and external (Rse) surface thermal resistance, given in this case by the PHPP according to its data. Lastly, the inverse value of the total resistance obtained is calculated, which is precisely the thermal transmittance of our component.

$$\mathrm{Rn} = \frac{\mathrm{e}}{\lambda} \quad ((\mathrm{m}^2 \cdot \mathrm{k})/\mathrm{W})$$

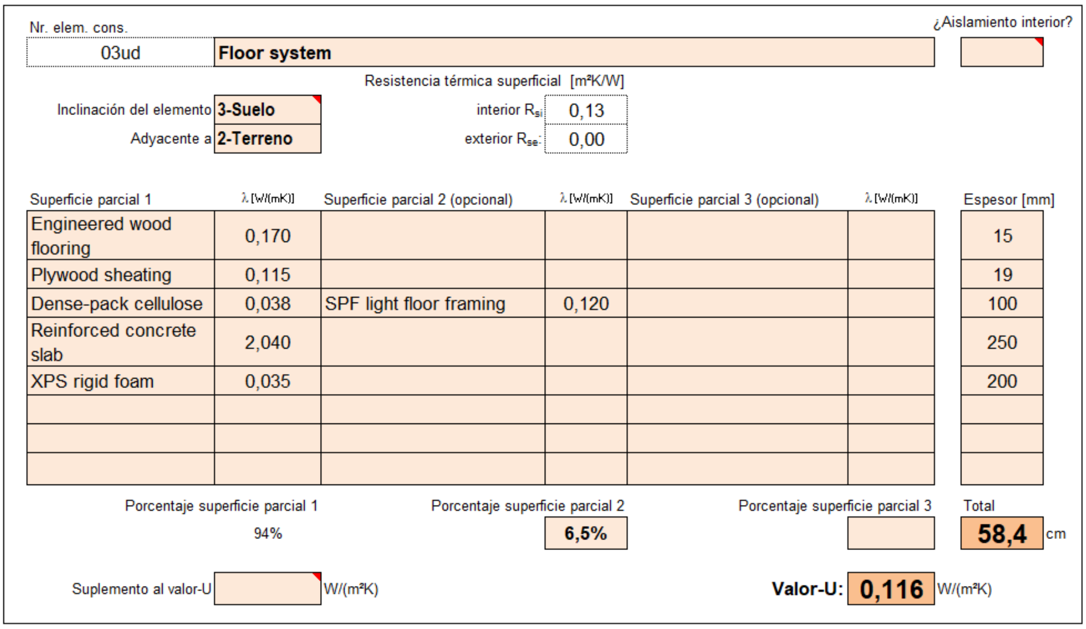
⬇

$$\mathrm{Rt} = \mathrm{Rsi} + \mathrm{Rse} + \sum \mathrm{Rni} \quad ((\mathrm{m}^2 \cdot \mathrm{k})/\mathrm{W})$$

⬇

$$\mathrm{Ut} = \frac{1}{\mathrm{Rt}} \quad (\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{k}))$$

The results obtained for the U-value of the floor system, the exterior walls, and the roof system of our project using the PHPP Excel spreadsheets are displayed in the following figures provided by that same software. The program creates a building component with the values entered for each of the constructive systems, which remains in its database and can be attributed to the different surfaces in the analysis of the building.



Nr. elem. cons. — ¿Aislamiento interior?

03ud — **Floor system**

Resistencia térmica superficial [m²K/W]

Inclinación del elemento **3-Suelo** — interior R_{si}: 0,13

Adyacente a **2-Terreno** — exterior R_{se}: 0,00

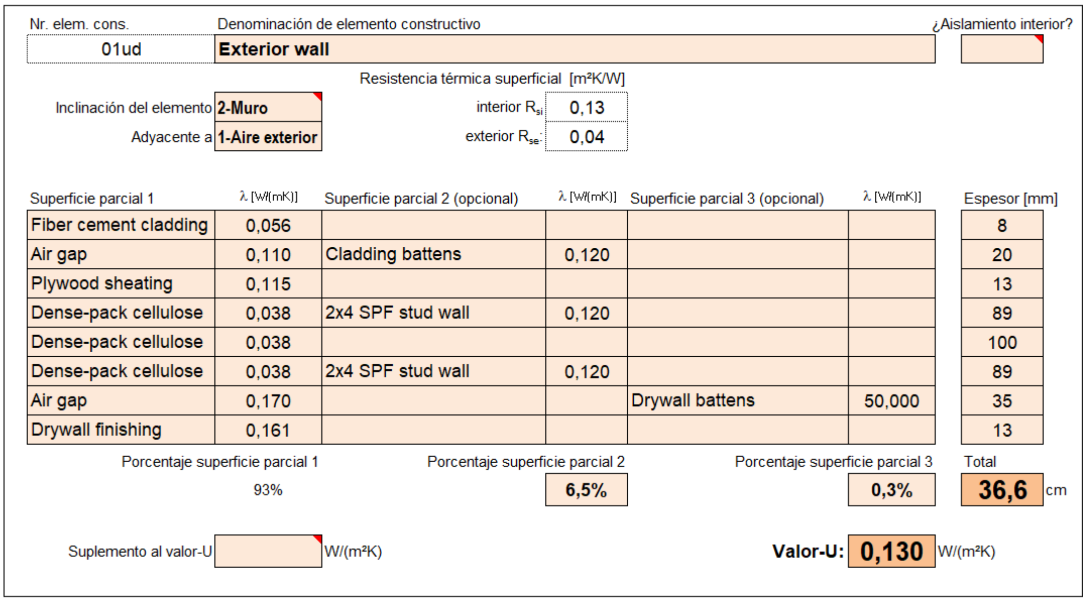
Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Engineered wood flooring	0,170					15
Plywood sheating	0,115					19
Dense-pack cellulose	0,038	SPF light floor framing	0,120			100
Reinforced concrete slab	2,040					250
XPS rigid foam	0,035					200

Porcentaje superficie parcial 1	Porcentaje superficie parcial 2	Porcentaje superficie parcial 3	Total
94%	6,5%		58,4 cm

Suplemento al valor-U W/(m²K)

Valor-U: 0,116 W/(m²K)

Figure 21. Floor system: U-value calculation (Source: PHPP_V9.6a).



Nr. elem. cons. — Denominación de elemento constructivo — ¿Aislamiento interior?

01ud — **Exterior wall**

Resistencia térmica superficial [m²K/W]

Inclinación del elemento **2-Muro** — interior R_{si}: 0,13

Adyacente a **1-Aire exterior** — exterior R_{se}: 0,04

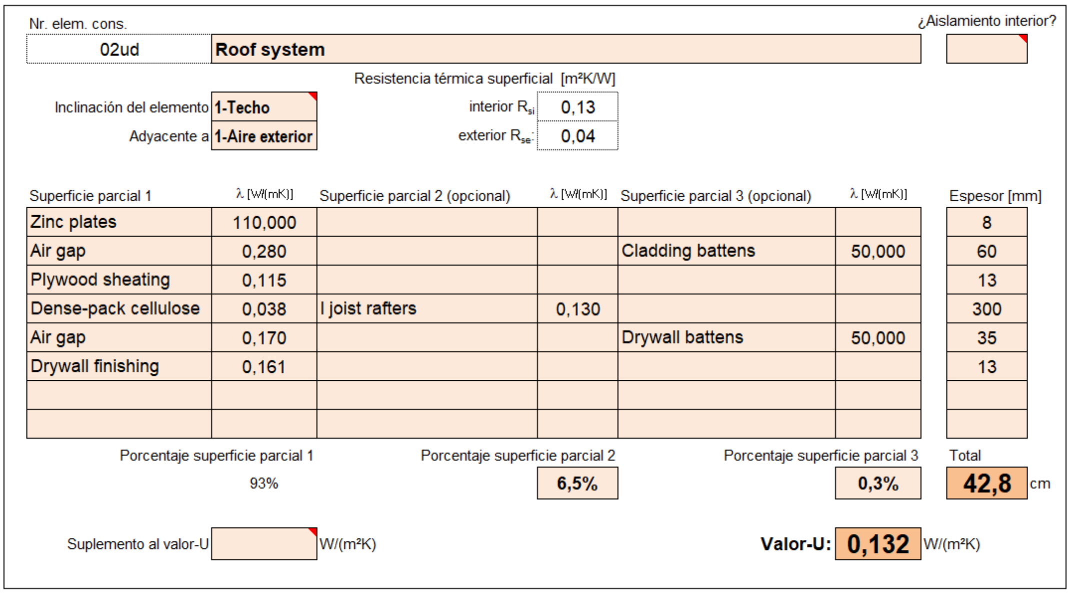
Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Fiber cement cladding	0,056					8
Air gap	0,110	Cladding battens	0,120			20
Plywood sheating	0,115					13
Dense-pack cellulose	0,038	2x4 SPF stud wall	0,120			89
Dense-pack cellulose	0,038					100
Dense-pack cellulose	0,038	2x4 SPF stud wall	0,120			89
Air gap	0,170			Drywall battens	50,000	35
Drywall finishing	0,161					13

Porcentaje superficie parcial 1	Porcentaje superficie parcial 2	Porcentaje superficie parcial 3	Total
93%	6,5%	0,3%	36,6 cm

Suplemento al valor-U W/(m²K)

Valor-U: 0,130 W/(m²K)

Figure 22. Exterior walls: U-value calculation (Source: PHPP_V9.6a).



Nr. elem. cons. ¿Aislamiento interior?

02ud	**Roof system**	

Resistencia térmica superficial [m²K/W]

Inclinación del elemento	**1-Techo**	interior R_{si}	0,13
Adyacente a	**1-Aire exterior**	exterior R_{se}:	0,04

Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Zinc plates	110,000					8
Air gap	0,280			Cladding battens	50,000	60
Plywood sheating	0,115					13
Dense-pack cellulose	0,038	I joist rafters	0,130			300
Air gap	0,170			Drywall battens	50,000	35
Drywall finishing	0,161					13

Porcentaje superficie parcial 1	Porcentaje superficie parcial 2	Porcentaje superficie parcial 3	Total
93%	**6,5%**	**0,3%**	**42,8** cm

Suplemento al valor-U W/(m²K)

Valor-U: **0,132** W/(m²K)

Figure 23. Roof system: U-value calculation (Source: PHPP_V9.6a).

Different trials were carried out on each element since the tool was used from the start, varying the insulation thicknesses according to the results obtained. Therefore, the configuration presented in the detail sections previously, as well as in the tables above, has been considered the most convenient for the model house scenario. Finally, once these three types of surfaces are identified in the PHPP as the building components, the energy modeling can be conducted with its overall analysis.

4.5. Energy Performance and PHPP Analysis

4.5.1. Modeling the Building: Design PH

One essential part of the analysis of the building is to create the corresponding modeling, known in the Passivhaus certification process as Design PH. The latter is a plugin created by the Passivhaus Institute for Sketchup software that allows a 3D surface-based modeling of the building to be tested. Therefore, this tool allows exporting to PHPP the necessary features of the project to be analyzed in a simplified way. The initial step is to enter the location and orientation of the project so that the tool adjusts the solar incidence angles and the corresponding climate data.

Afterward, the thermal envelope of the house is modeled in a simplified version, consisting of surfaces without depth and with no need to include any of the interior partitions. For each of the surfaces created, a specific character has to be assigned from among the various options offered by the software, and in this practical case, there are three different types: exterior wall, sill, and roof. Once this base model is correctly categorized, the existing windows are inserted and assigned the type of glass and frame chosen, entering all of their needed data. The more accurate the modeling, the better the precision of the analysis done later on in the PHPP.

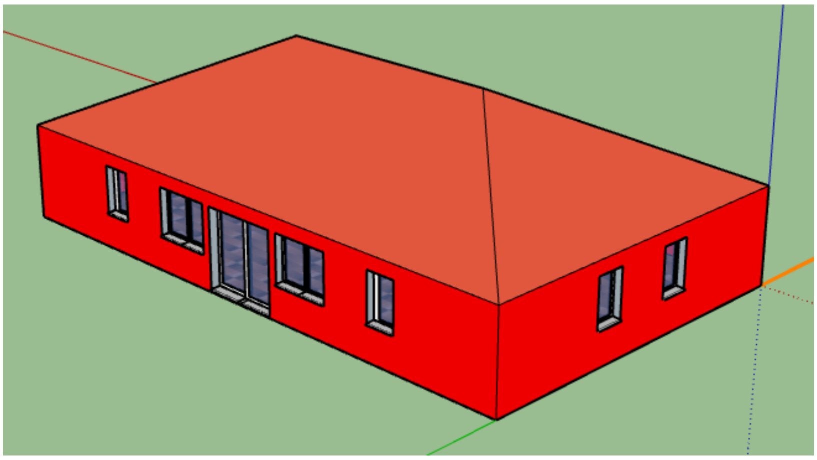


Figure 24. Thermal building envelope modeling with DesignPH. Own elaboration.

Before completing this pre-analysis work, additional modeling is needed to include any solar shading that may affect the building envelope. In climates such as Oklahoma, where passive solar shading must be considered in the warmer months to avoid overheating, the shading elements play a critical role in the performance of our building. Generally, the standard allows the inclusion of shadows cast by the surroundings (e.g. nearby buildings, vegetation, etc.), although only elements of the house itself are included in this case. Thus, both the roof overhang and the rear porch have been incorporated, along with the volume of the garage, not included inside the thermal envelope.

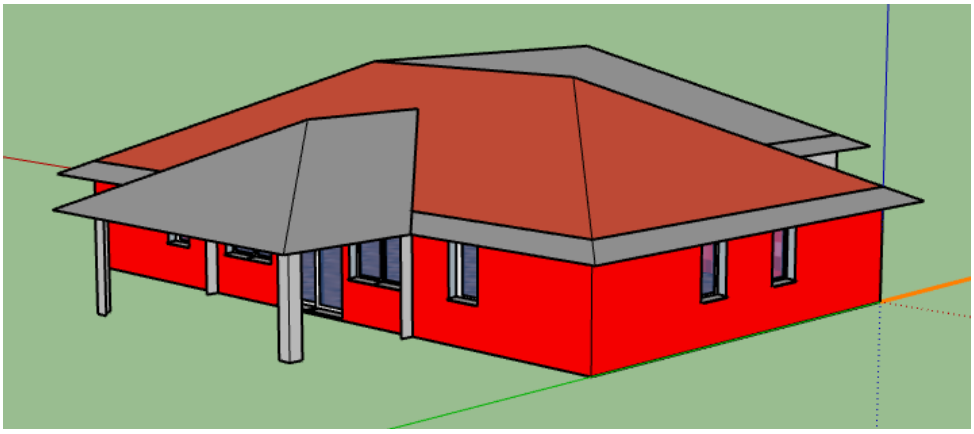


Figure 25. Complete envelope modeling with shading elements with Design PH. Own elaboration.

Once the modeling of the project is completed, an analysis of the project has to be performed with the Design PH plugin. Upon completion, an export file is created containing all the relevant data, such as the area of each envelope surface, the windows' dimensions and settings, and the details provided by the orientation study of all these elements. At this point, this file can be exported directly to the PHPP, where the complete analysis will be performed.

4.5.2. PHPP Energy Efficiency Performance Analysis

In this section, the final stage of the certification of a project is reached. The PHPP is a sophisticated tool that enables the designer to verify whether the requirements established by the Standard for the specific climate are fulfilled and by what scope. As previously mentioned, this analysis is recommended to guide the entire design process, however, once the final decisions have been made it also determines the validity of the chosen solution. An official certifying entity must always review the results of this process and grant the official certification to the project. Essentially, for this to happen the PHPP has to verify compliance with the maximum heating and cooling loads (or the maximum demands in its absence), and also check the airtightness and renewable primary energy demand values are within the established limits. However, since this is an unbuilt project, the hermeticity-related check cannot be completed because of the impossibility of carrying out the BlowerDoor test. For the data and results in this case study the PHPP version 9.6a will be used in Spanish, consequently, the final report will be in this language.

Before checking all the above-mentioned aspects, the first step is to insert the modeling created using the Design PH and to make all the relevant checks. For this, we import the data into the PHPP file and ensure that the selected climate is correct. After importing and to avoid any discrepancies affecting the calculations, we double-check that the surface areas and window dimensions match those set in SketchUp. After all the information about the project geometry is accurate, a U-value is assigned to each envelope component based on the calculations performed for each of them. By doing this, all the design parameters of our building would be reflected in the PHPP and thus allow us to proceed with the analysis of the building.

The next step is to determine the necessary systems based on the project’s solution. The initial results generated by the PHPP, after simply inputting the characteristics of our building envelope, are sufficient to reflect these needs and guide the decision-making process, as they consider various aspects. The PHPP evaluates whether the thermal transmission of the building envelope, the amount of solar energy entering the building and how it is managed, and the temperature of internal surfaces are appropriate to minimize demand and maximize interior comfort. Similarly, thermal bridges in the envelope should be studied and accounted for to ensure they do not negatively impact performance. However, due to the limitations of this Final Degree Project, this aspect has not been explored in depth. Thus, without the need to introduce any active climate control systems, it is possible to assess the project's demands and make informed decisions since these results indicate the energy needs that the building requires to maintain thermal comfort. For the model house, the demand results were within the established range, which is indicative of the adequacy of the chosen solutions.

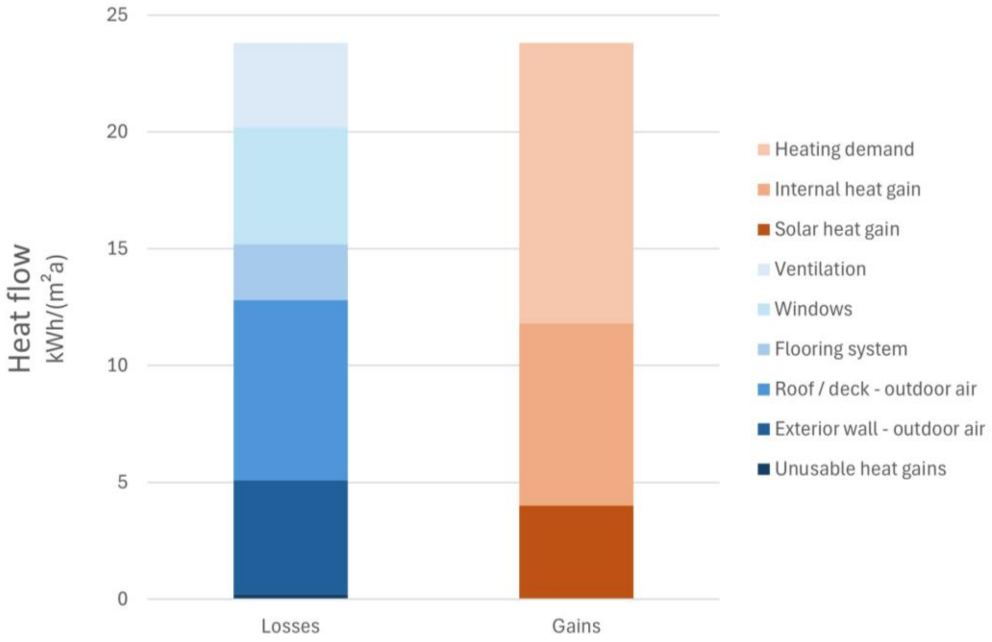


Figure 26. Annual energy balance of heating demand bar graph (Source: PHPP_V9.6a).

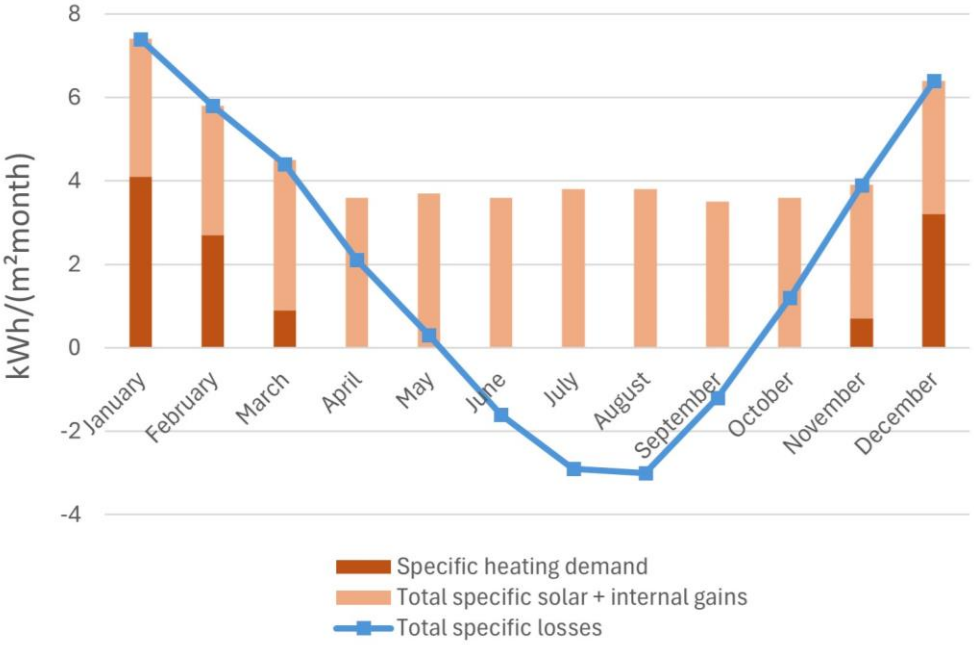


Figure 27. Monthly heating demand graph (Source: PHPP_V9.6a).

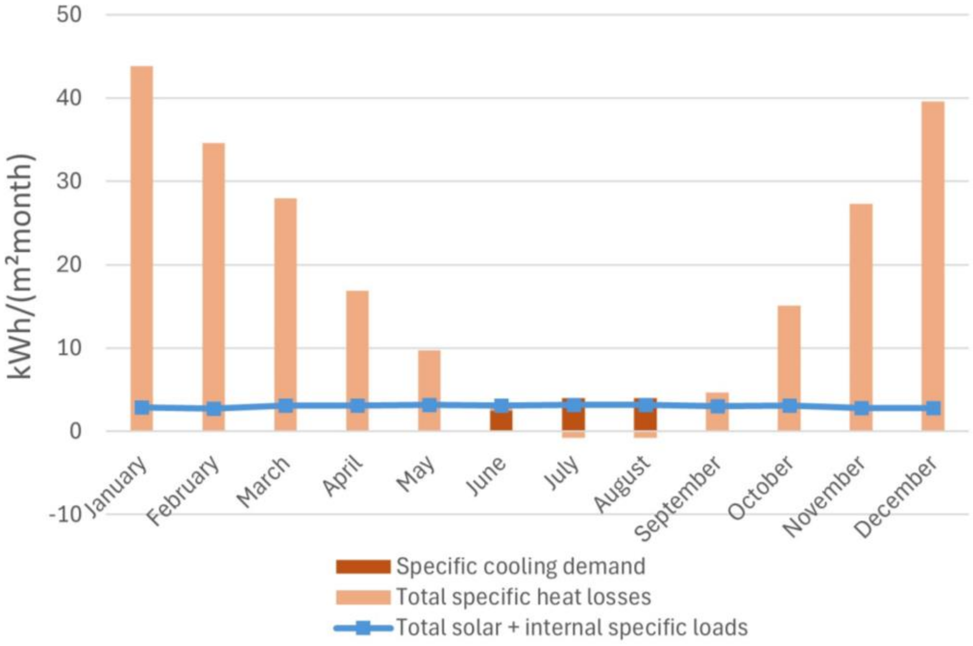


Figure 28. Monthly specific usable cooling demand graph (Source: PHPP_V9.6a).

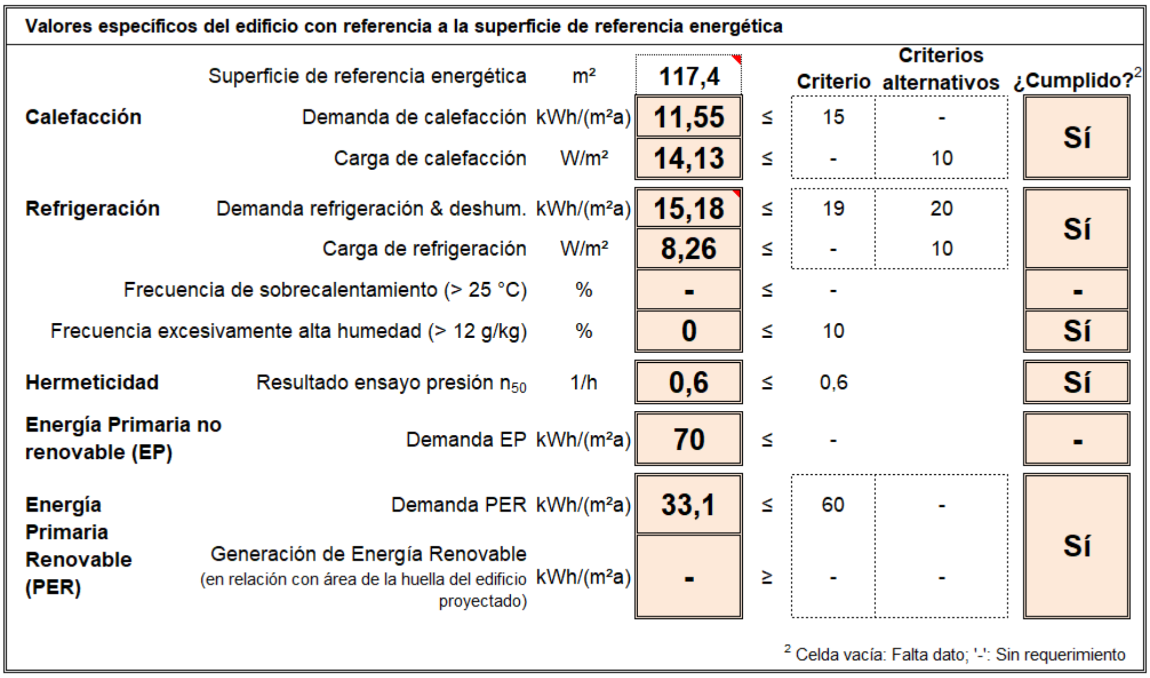
On this basis, it is decided which systems will be used to meet these demands. The selected pieces of equipment must be efficient and compatible with the requirements of the Passivhaus standard. To begin, following the design principles of the Passivhaus Standard, a mechanical ventilation system with heat recovery (MVHR) will be implemented in the house. This key component of Passivhaus design ensures excellent indoor air quality, minimizes heat loss, and maintains thermal comfort, all with low energy consumption. Additionally, to enhance ventilation and provide an alternative cooling method during warmer nights, the possibility of incorporating cross-ventilation has been considered by facilitating airflow through the house by opening windows located on the east and west façades.

To cover heating and cooling demands in an efficient and compatible way with the high energy performance standards required by this type of construction, it was decided to use a 2x1 ducted climate control system. While Passivhaus homes are designed to minimize energy demand through a highly efficient envelope and a mechanical ventilation system with heat recovery (MVHR), in more extreme climates or specific situations, additional systems may be needed to ensure thermal comfort. This system is an air conditioning and heating solution that combines an outdoor unit with two indoor ones connected through a duct network. The use of ducts allows a more even distribution of air, providing greater thermal comfort inside the dwelling. This system must be well integrated with the chosen ventilation system.

After the HVAC systems are specified and the home's heating and cooling demand is met, the last requirement is the primary energy demand check. This restricts the total amount of primary energy used by the home, including heating, cooling, hot water, electricity, and appliances. When considering total energy consumption regardless of the source, the limit set by the standard is 120 kWh/m²/year. However, in this practical case, it is intended to verify renewable primary energy, whose limitation is reduced by half. The aim is for the house not only to be energy efficient but to consume the lowest possible amount of non-renewable energy. Therefore, for the model house, the renewable primary energy needs have been calculated by estimating those used for the chosen heating, cooling, and dehumidification systems, while also estimating the demand for domestic hot water generation and electricity. The use of an air source heat pump (ASHP) system for hot water production has been assumed and the electricity needs have been predicted based on the characteristics of the dwelling. By knowing the dimensions and layout of the project, these assumptions can be considered close to reality. In addition, it is important to point out the insulation of pipes carrying hot water and ducts involved in heating or cooling inside the envelope. Such practice helps to maximize energy efficiency, maintain the desired indoor temperature, and prevent potential problems such as condensation.

Finally, the results can be analyzed after all the decision-making and entering the necessary information in the PHPP. As shown in Figure XX below containing the validation of the collected results in Spanish, the projected house heating demand is 11.55 kWh/(m²a), a value below the 15 kWh/(m²a) established as a limit by the Standard. Similarly, the cooling and dehumidification needs are 15.18 kWh/(m²a), below the 19 kWh/(m²a) set for Oklahoma's specific climate.

In addition, having the most appropriate equipment for the area and the dwelling reduces the excessive frequency of high humidity to zero. Lastly, the primary renewable energy demand is also below the limit, with a value of 33.1 kWh/(m²a).



Valores específicos del edificio con referencia a la superficie de referencia energética

					Criterio	Criterios alternativos	¿Cumplido?[2]
	Superficie de referencia energética	m²	117,4				
Calefacción	Demanda de calefacción	kWh/(m²a)	11,55	≤	15	-	Sí
	Carga de calefacción	W/m²	14,13	≤	-	10	
Refrigeración	Demanda refrigeración & deshum.	kWh/(m²a)	15,18	≤	19	20	Sí
	Carga de refrigeración	W/m²	8,26	≤	-	10	
	Frecuencia de sobrecalentamiento (> 25 °C)	%	-	≤	-		-
	Frecuencia excesivamente alta humedad (> 12 g/kg)	%	0	≤	10		Sí
Hermeticidad	Resultado ensayo presión n_{50}	1/h	0,6	≤	0,6		Sí
Energía Primaria no renovable (EP)	Demanda EP	kWh/(m²a)	70	≤	-		-
Energía Primaria Renovable (PER)	Demanda PER	kWh/(m²a)	33,1	≤	60	-	Sí
	Generación de Energía Renovable (en relación con área de la huella del edificio proyectado)	kWh/(m²a)	-	≥	-	-	

[2] Celda vacía: Falta dato; '-': Sin requerimiento

Figure 29. Final report on the specific values of the building and its compliance with Passivhaus requirements (Source: PHPP_V9.6a).

Consequently, it can be assumed that the model house meets the strict Passivhaus requirements and could be certified as such according to the values obtained as a result of the PHPP performance analysis. Furthermore, this verifies the effectiveness of the proposed construction solutions, tailored to the local conditions and specific climate requirements.

5. CONCLUSION

5.1. Summary of Findings and Contributions

This Final Degree Project sought to explore the possibility of integrating the Passivhaus Standard to the climatic conditions of Oklahoma, in the United States. The focus of this state was selected primarily for the absence of such practices in the area, well known for its high residential energy consumption due to a challenging climate. Coming in fairly low in national energy efficiency rankings, implementing this approach in its residential cores could potentially improve the lives of Oklahomans and perhaps provide significant economic savings for households with below-average median incomes. By conducting an in-depth analysis of the regional climate and housing characteristics, and applying the Standard through a case study, this research aims to demonstrate how these types of environmentally responsible approaches can be successfully pursued in this context.

The findings of the design and analysis of a viable Passivhaus house in the Oklahoma context reveal the relevance of several aspects to optimize the energy efficiency of a house in this type of climate. First, it is essential to be aware of the need for the design to respond to a appropriate orientation on which its layout should depend. Secondly, one must be particularly careful when defining the openings, their position, and dimensions, since it is crucial to pay special attention to solar gains and their management. Lastly, along the same lines, the provision of strategic shading can have a significant impact on energy demands whilst maintaining comfort inside the dwelling. All these considerations regarding the design of a single-family detached house have a greater impact on the result than one might expect.

Besides all the above, this paper provides a constructive solution as an example that has been proven valid through the software provided by the Passivhaus Institut itself. The latter establishes a solid base about the insulation levels required by this specific climate in the various components of the building envelope of such a specific type of construction. According to what has been analyzed, the insulation levels in the different components of the envelope that would facilitate obtaining an appropriate result for Passivhaus certification in Oklahoma would be around 300 mm. Part of this insulation, or as in the case of the roof, all of it, could be incorporated into the wood framing structural system itself. The different elements created for this case study, still, are valid with some leeway so that perhaps the thickness could be reduced. In any case, thanks to the transmittance calculations for each of them, it is clear that values lower than 0.13 $W/(m^2K)$ should give a satisfactory performance for components in contact with the outside air, while a value close to 0.11 $W/(m^2K)$ would be necessary for those in contact with the ground. Thus, based on these compositions, a guideline can be provided for future variations that may wish to address similar needs. Likewise, an indicative idea of potential solutions for heating, cooling, ventilation, and domestic hot water demands is presented as an admissible option.

While aware of the limitations of this research, it nonetheless contributes to the expanding of knowledge on sustainable residential architecture by providing a practical framework for the application of energy efficiency standards in the area. The information gathered and the analysis performed provide insights that may be valuable on the design considerations required to ensure energy efficiency in comparable environments and contexts. However, while this research has contributed to the adaptation of the Passivhaus standard in Oklahoma, the long-term viability of such buildings in the region needs to be further studied. In addition, there may be an opportunity to go a step further in passive architecture by finding even more site-specific demand reduction strategies. Based on these results, the implementation of more sustainable architecture in Oklahoma can continue to evolve and become a reality accessible to all.

5.2. Correlation Between the Discussed Topic and the Sustainable Development Goals (SDGs).

In a world where discussions about sustainability are on the agenda, the consequences of climate change continue to be a major issue of concern to many. This situation to which our planet is exposed is one of the main topics addressed by the Sustainable Development Goals (SDGs). The SDGs are a list of 17 global goals established in 2015 by the United Nations as part of the 2030 Agenda addressing issues such as poverty, social inequality, peace, justice, and the climate emergency.

Along with the entire construction sector, the direct impact of architecture is undeniable on several of the subjects included in this list of targets. More than ever, professionals must commit to the pursuit of environmentally responsible architecture practices, lowering the impact they have on the planet. Certain initiatives, such as the emergence of the Passivhaus Standard, represent changes in the right direction, yet they are not always capable of reaching everywhere, regardless of their increasing popularity. Therefore, it is interesting to open research paths to make this kind of practice available in those areas where a change of path is needed. In the case presented in this paper, Oklahoma is chosen as a case study, being one of the 50 states of the United States of America which has been considered interesting due to its adverse climatology and the absence of policies supporting the general acceptance of such practices.

Essentially, the purpose of the Passivhaus Standard is for buildings to achieve their highest possible levels of energy efficiency based on a set of well-defined requirements, thereby contributing directly to reducing consumption and, therefore, the emissions that cause the so-called "greenhouse effect". Hence, it becomes synonymous with the pursuit of environmental sustainability and, as mentioned in Goal 7, a guarantee of access to affordable and clean energy for the population. What is more, thinking on a larger scale, the adaptation of these principles to the state of Oklahoma could mean, at best, the creation of safer and more sustainable cities, as stated in Goal 11. Tailoring buildings to the standard would enhance the appearance of more resilient and resistant urban cores when faced with site-specific climatic conditions, characterized by adverse weather events (storms, tornadoes, heat waves, etc.). Additionally, even though the integration of these principles in a specific place is a local action, it still marks a step forward in the necessary redirection of the sector to which architecture is a major contributor. In fact, in the case of a state like Oklahoma, the effect could be significant given that the latter has one of the worst positions in terms of energy efficiency in the United States. Thus, related to Goal 13, it would undoubtedly be an action for the climate.

Overall, the research on integrating the Passivhaus standard with local climate considerations in Oklahoma shows a direct commitment to the United Nations Sustainable Development Goals. Its emphasis on energy efficiency and promoting environmentally responsible and economically viable building practices contribute to several of the Global Goals, establishing a model for urban development not only at this location but also transferable to locations under similar conditions.

5.3. Suggestions for Future Research and Implementation

The more research on the feasibility of such practices in Oklahoma, the greater the growth in the interest of practitioners and users in pursuing them. Hence, it would be of great interest to develop analyses focused on the short and long-term economic viability of this type of residential construction, comparing such parameters with those of a common dwelling.

In the same way, the different strategies adopted to guarantee high levels of energy efficiency could be optimized to achieve improved results. Further study of the envelope's thermal bridges and their effects could lead to finding more suitable solutions with a stronger basis.

Further exploration of passive strategies for tasks such as indoor ventilation or surface temperature reduction in warmer periods would undoubtedly be another area of interest. While this would lead to an improvement in demand results, it additionally could improve the management of problems related to overheating or excessive frequency of high humidity.

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7. APPENDICES

APPENDICE A.

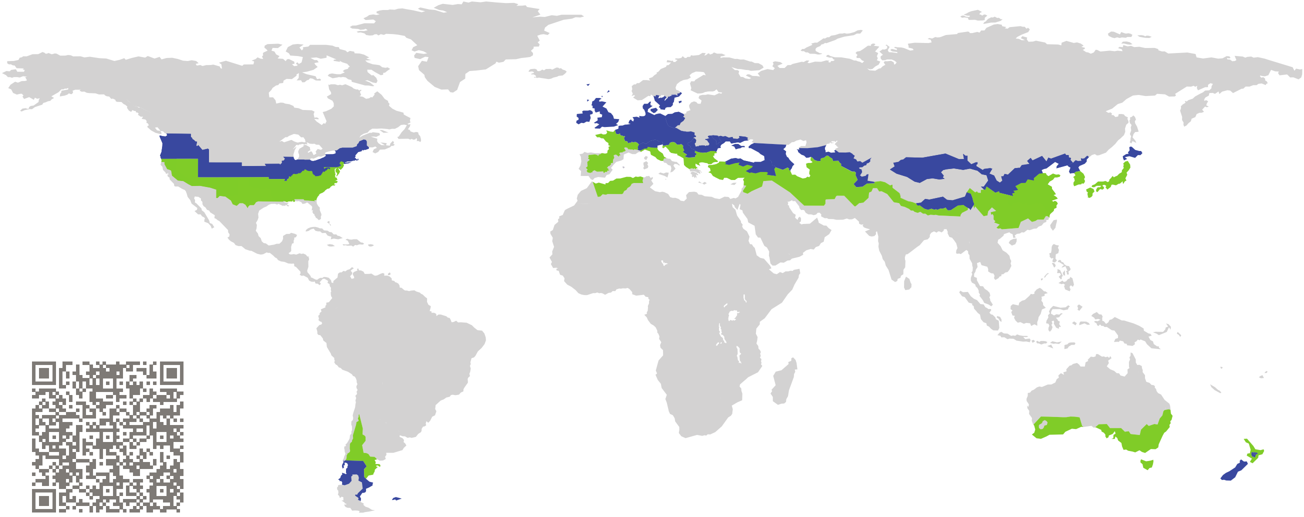
Official Passivhaus certificates of the window and door components used in the model home.

CERTIFICATE

Certified Passive House Component

Component-ID 0905ws03 valid until 31st December 2024

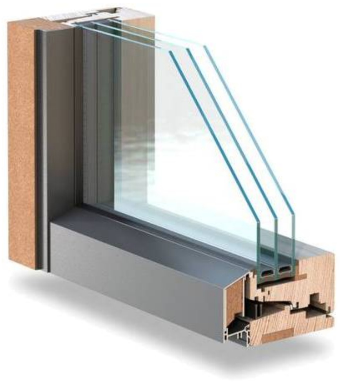
Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany



Category: **Window system**

Manufacturer: **pro Passivhausfenster GmbH,**
Oberaudorf,
Germany

Product name: **smartwin**



This certificate was awarded based on the following criteria for the cool, temperate climate zone

Comfort	$U_W = 0.77$	$\leq$	$0.80\ \mathrm{W/(m^2 \cdot K)}$
	$U_{W,\mathrm{installed}}$	$\leq$	$0.85\ \mathrm{W/(m^2 \cdot K)}$
	with U_g	$=$	$0.70\ \mathrm{W/(m^2 \cdot K)}$
Hygiene	$f_{Rsi=0.25}$	$\geq$	0.70
Airtightness	$Q_{100} = 0.11$	$\leq$	$0.25\ \mathrm{m^3/(h \cdot m)}$

cool, temperate climate

phA

CERTIFIED COMPONENT

Passive House Institute

Passive House efficiency class	phE	phD	phC	phB	phA

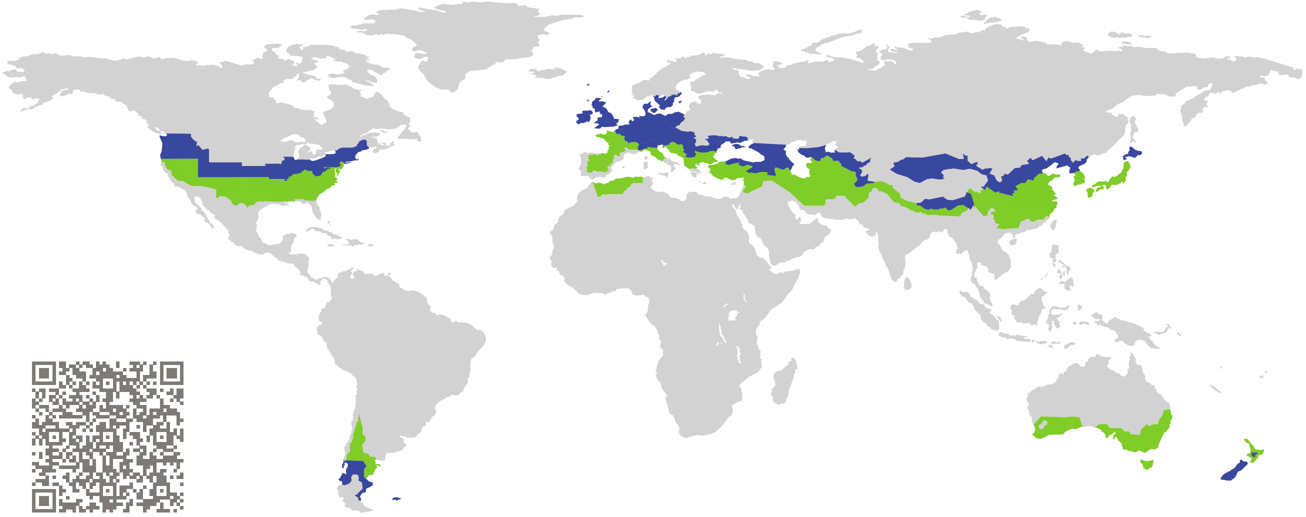
www.passivehouse.com

CERTIFICATE

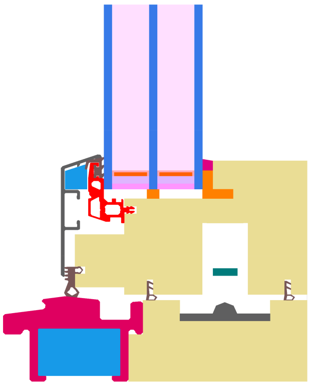
Certified Passive House Component

Component-ID 0399sl03 valid until 31st December 2024

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany



Category:	**Sliding Door**
Manufacturer:	**pro Passivhausfenster GmbH, Oberaudorf, Germany**
Product name:	**smartwin sliding**



This certificate was awarded based on the following criteria for the cool, temperate climate zone

Comfort $U_{SL} = 0.78 \leq 0.80\,\mathrm{W/(m^2 \cdot K)}$
$U_{SL,\mathrm{installed}} \leq 0.85\,\mathrm{W/(m^2 \cdot K)}$
with $U_g = 0.70\,\mathrm{W/(m^2 \cdot K)}$

Hygiene $f_{Rsi=0.25} \geq 0.70$

cool, temperate climate

phA

CERTIFIED COMPONENT

Passive House Institute

Passive House efficiency class	phE	phD	phC	phB	phA

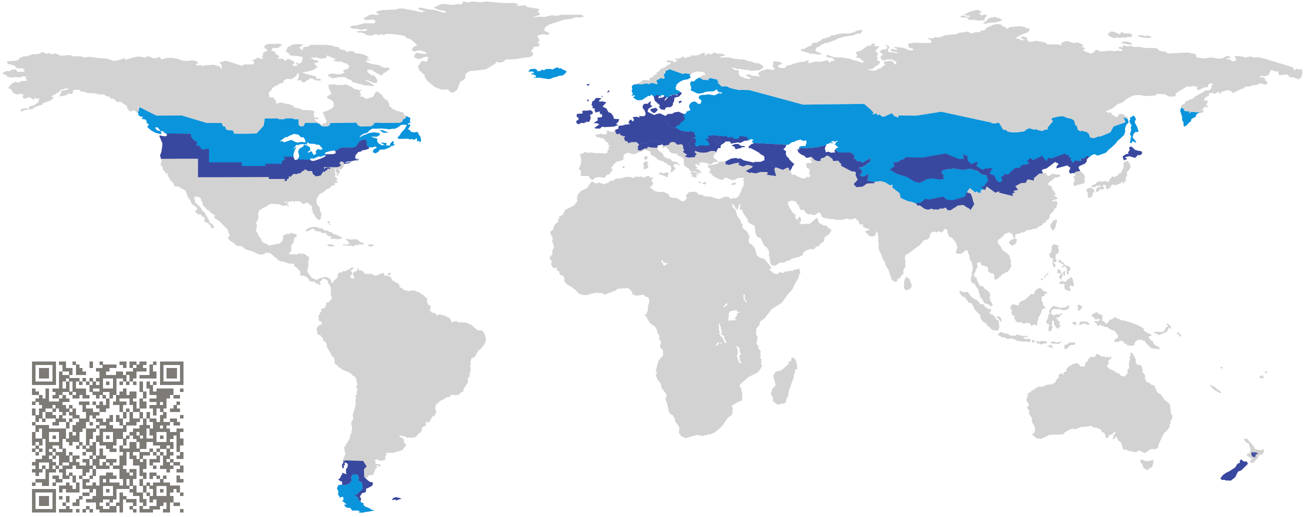
www.passivehouse.com

CERTIFICATE

Certified Passive House Component

Component-ID 1109ds02 valid until 31st December 2024

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany



Category: **Door system**

Manufacturer: **pro Passivhausfenster GmbH**
Oberaudorf
Germany

Product name: **smartwin entrance**

(Inward opening)

This certificate was awarded based on the following criteria for the cold climate zone

Comfort	$U_D = 0.51$	$\leq$	$0.60\,\mathrm{W/(m^2 \cdot K)}$
	$U_{D,\text{installed}}$	$\leq$	$0.65\,\mathrm{W/(m^2 \cdot K)}$
	with $U_{\text{door leaf}}$ [1]	$=$	$0.33\,\mathrm{W/(m^2 \cdot K)}$
Hygiene	$f_{Rsi=0.25}$	$\geq$	0.75
Airtightness	$Q_{100} = 0.6$	$\leq$	$2.25\,\mathrm{m^3/(h \cdot m)}$

cold climate

CERTIFIED COMPONENT

Passive House Institute

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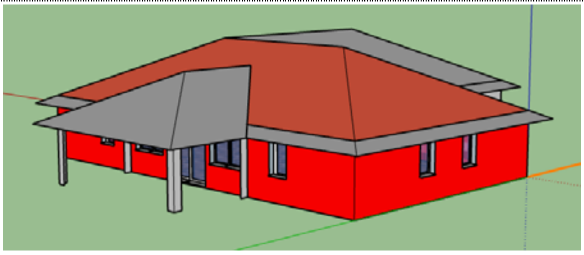
[1] U-value of the insulated area of door leaf

APPENDICE B.

Final PHPP report on the model home analysis.

Casa Pasiva Comprobación



Edificio: Casa Passivhaus modelo para Oklahoma
Calle:
CP / Ciudad: Oklahoma City
Provincia/País: US-Estados Unidos de América (los)
Tipo de edificio: Vivienda unifamiliar aislada
Datos climáticos: US0061a-Oklahoma City
Zona climática: 4: Cálida-templada Altitud de la localización: 270 m

Propietario / cliente:
Calle:
CP / Ciudad:
Provincia/País:

Arquitectura:
Calle:
CP / Ciudad:
Provincia/País:

Ingeniería:
Calle:
CP / Ciudad:
Provincia/País:

Consult. energética:
Calle:
CP / Ciudad:
Provincia/País:

Certificación:
Calle:
CP / Ciudad:
Provincia/País:

Año construcción:	2024	Temp. interior invierno [°C]:	20,0	Temp. interior verano [°C]:	25,0
Nr. de viviendas	1	Ganancias internas de calor (GIC); caso calefacción [W/m^2]:	2,5	GIC caso refrig. [W/m²]:	2,6
Nr. de personas:	2,6	Capacidad específica [Wh/K por m² de SRE]:	132	Refrigeración mecánica:	x

Valores específicos del edificio con referencia a la superficie de referencia energética

					Criterio	Criterios alternativos	¿Cumplido?[2]
	Superficie de referencia energética	m²	117,4				
Calefacción	Demanda de calefacción	kWh/(m²a)	11,55	≤	15	-	Sí
	Carga de calefacción	W/m²	14,13	≤	-	10	
Refrigeración	Demanda refrigeración & deshum.	kWh/(m²a)	15,16	≤	19	20	Sí
	Carga de refrigeración	W/m²	8,25	≤	-	10	
	Frecuencia de sobrecalentamiento (> 25 °C)	%	-	≤	-		-
	Frecuencia excesivamente alta humedad (> 12 g/kg)	%	0	≤	10		Sí
Hermeticidad	Resultado ensayo presión n_{50}	1/h	0,6	≤	0,6		Sí
Energía Primaria no renovable (EP)	Demanda EP	kWh/(m²a)	83	≤	-		-
Energía Primaria Renovable (PER)	Demanda PER	kWh/(m²a)	38	≤	60	-	Sí
	Generación de Energía Renovable (en relación con área de la huella del edificio proyectado)	kWh/(m²a)	-	≥	-	-	

[2] Celda vacía: Falta dato; '-': Sin requerimiento

Confirmo que los valores aquí presentados han sido determinados siguiendo la metodología de PHPP y están basados en los valores característicos del edificio. Los cálculos de PHPP están adjuntos a esta comprobación.

¿Casa Pasiva Classic? Sí

Función:
Nombre: rafael
Apellido: ortega
Firma:
Emisión:
Ciudad:

Datos de proyecto importados desde desighPH 2.1.15 2024-08-28 15:43:12 +0200 Código desplegado PHPP9:

Datos climáticos

#¡VALOR!

Selección de los datos climáticos

País:	US
Región:	Todas
	1-Sortierung: Alphabetisch
Datos climáticos:	US0061a
Zona climática:	4: Cálida-templada

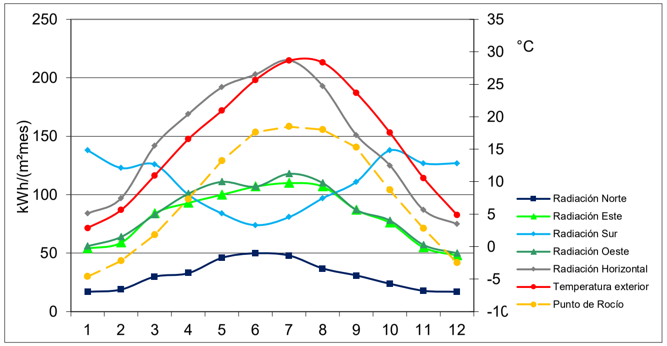
Altitud

Estación climática:	365,0	m
Ubicación del edificio:	270	m

Visión general de los resultados

Demanda de calefacción	11,5	kWh/(m²a)
Carga de calefacción	14,1	W/m²
Frecuencia sobrecalentamiento	-	%
Refrigeración sensible	10,6	kWh/(m²a)
Refrigeración latente	4,6	kWh/(m²a)
Carga de refrigeración	8,2	W/m²
Demanda PER	38,5	kWh/(m²a)

	Datos para calefacción Método anual	Datos método mensual Calefacción	Refrigeración	
Periodo calef. / refrig.	128	151	122	d/a
Grados hora calef. / refrig.	44	53	2	kKh/a
Radiación Norte	78	101	166	kWh/(m²a)
Radiación Este	234	300	411	kWh/(m²a)
Radiación Sur	522	641	363	kWh/(m²a)
Radiación Oeste	243	310	422	kWh/(m²a)
Radiación Horizontal	376	485	762	kWh/(m²a)



	Mes	1	2	3	4	5	6	7	8	9	10	11	12	Carga de calefacción		Carga de refrigeración		PER	
	Días	31	28	31	30	31	30	31	31	30	31	30	31	Sit. met.1	Sit. met. 2	Sit. met.1	Sit. met. 2	factores	
	US0061a-Oklahoma City	Latitud °	35,5	Longitud °	-97,6	Altitud [m]	365	Fluctuación diaria temperatura en verano [K]			12,6			Radiación: [W/m²]		Radiación: [W/m²]			
° C	Temperatura exterior	2,9	5,7	11,0	16,6	21,0	25,7	28,7	28,4	23,7	17,6	10,6	4,9	-8,9	-6,2	33,6	33,6	1,20	Electricidad doméstica
kWh/(m²mes)	Radiación Norte	17	19	30	33	46	50	48	37	31	24	18	17	35	30	90	90	1,15	ACS
kWh/(m²mes)	Radiación Este	54	59	84	93	100	107	110	107	87	76	55	48	35	30	190	190	1,90	Calefacción
kWh/(m²mes)	Radiación Sur	138	123	126	100	84	74	81	97	111	138	127	127	40	30	170	170	1,45	Refrigeración
kWh/(m²mes)	Radiación Oeste	56	64	83	101	111	107	118	110	87	78	57	50	35	30	180	180	1,65	Deshumidificación
kWh/(m²mes)	Radiación Horizontal	84	97	142	169	192	203	215	193	151	125	87	75	50	40	350	350		
° C	Punto de Rocío	-4,6	-2,2	1,8	7,3	13,2	17,6	18,5	18,0	15,3	8,7	2,8	-2,5			21,5	21,5		
° C	Temperatura del cielo	-20,6	-14,4	-5,1	3,7	10,9	16,0	17,9	17,0	11,7	0,6	-10,1	-18,3			20,2	21,5		
° C	Temperatura terreno	13,7	12,3	12,3	13,6	16,0	18,9	21,3	22,8	22,8	21,4	19,0	16,2	12,2	12,2	22,9	22,9		
	Comentario:	Source: Meteonorm																	

-

Valor-U de los sistemas constructivos

#

Cálculo secundario: Conductividad térmica equivalente de los espacios de aire en calma -> (a la derecha)
Capas en forma de cuña (aislamiento con pendiente)
Capas de aire sin ventilar y áticos no calefactados

Nr. elem. cons.	Denominación de elemento constructivo	¿Aislamiento interior?
01ud	**Pared exterior**	

Resistencia térmica superficial [m²K/W]

Inclinación del elemento	2-Muro	interior R_{si}	0,13
Adyacente a	1-Aire exterior	exterior R_{se}:	0,04

Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Placas fibrocemento	**0,056**					**8**
Cámara de aire	**0,110**	**Rastreles acabado**	**0,120**			**20**
Tablero madera contrachapada	**0,115**					**13**
Aislante de celulosa	**0,038**	**Montante madera 2x4 in**	**0,120**			**89**
Aislante de celulosa	**0,038**					**100**
Aislante de celulosa	**0,038**	**Montante madera 2x4 in**	**0,120**			**89**
Cámara de aire	**0,170**			**Perflería PYL**	**50,000**	**35**
PYL	**0,161**					**13**

Porcentaje superficie parcial 1	Porcentaje superficie parcial 2	Porcentaje superficie parcial 3	Total
93%	**6,5%**	**0,3%**	**36,6** cm

Suplemento al valor-U W/(m²K)

Valor-U: 0,130 W/(m²K)

Nr. elem. cons.		¿Aislamiento interior?
02ud	**Cubierta inclinada**	

Resistencia térmica superficial [m²K/W]

Inclinación del elemento	1-Techo	interior R_{si}	0,13
Adyacente a	1-Aire exterior	exterior R_{se}:	0,04

Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Planchas zinc	**110,000**					**8**
Cámara de aire	**0,280**			**Perfilería planchas**	**50,000**	**60**
Tablero madera contrachapada	**0,115**					**13**
Aislante de celulosa	**0,038**	**Viga en I madera**	**0,130**			**300**
Cámara de aire	**0,170**			**Perflería PYL**	**50,000**	**35**
PYL	**0,161**					**13**

Porcentaje superficie parcial 1	Porcentaje superficie parcial 2	Porcentaje superficie parcial 3	Total
93%	**6,5%**	**0,3%**	**42,8** cm

Suplemento al valor-U W/(m²K)

Valor-U: 0,132 W/(m²K)

Nr. elem. cons.		¿Aislamiento interior?
03ud	**Solera**	

Resistencia térmica superficial [m²K/W]

Inclinación del elemento	3-Suelo	interior R_{si}	0,13
Adyacente a	2-Terreno	exterior R_{se}:	0,00

Superficie parcial 1	λ [W/(mK)]	Superficie parcial 2 (opcional)	λ [W/(mK)]	Superficie parcial 3 (opcional)	λ [W/(mK)]	Espesor [mm]
Suelo de madera	**0,170**					**15**
Tablero madera contrachapada	**0,115**					**19**
Aislante de celulosa	**0,038**	**Rastrelado madera**	**0,120**			**100**
Losa de HA	**2,040**					**250**
Aislante XPS	**0,035**					**200**

Porcentaje superficie parcial 1 Porcentaje superficie parcial 2 Porcentaje superficie parcial 3 Total

94%	6,5%		58,4 cm
Suplemento al valor-U	W/(m²K)	**Valor-U:**	**0,116** W/(m²K)

Determinación de superficies

#####

Cuadro resumen

Zona de temperatura	Grupo de superficies	Nr. de grupo	Superficie / Longitud	Unidad	Comentario	Resumen de los elementos constructivos	Valor-U, promedio [W/(m²K)]	Ganancias por radiación periodo de calefacción [kWh/a] 5 Meses	Ganancias por radiación periodo de calefacción [kWh/a] 4 Meses
	SRE (sup. de referencia energética)	1	**117,42**	m²	*Superficie de referencia energética de acuerdo a manual PHPP.*				
A	**Ventanas al norte**	2	**5,06**	m²	Los resultados vienen de la hoja 'Ventanas' Las superficies de ventanas se sustraen de las superficies opacas automáticamente son mostradas en la hoja 'Ventanas'	**Ventanas al norte**	**0,613**	**15**	**9**
A	**Ventanas al este**	3	**1,86**	m²		**Ventanas al este**	**0,760**	**86**	**43**
A	**Ventanas al sur**	4	**9,85**	m²		**Ventanas al sur**	**0,754**	**380**	**139**
A	**Ventanas al oeste**	5	**1,86**	m²		**Ventanas al oeste**	**0,739**	**107**	**52**
A	**Ventanas horizontales**	6	**0,00**	m²		**Ventanas horizontales**			
A	**Puerta exterior**	7	**0,00**	m²	*Restar la superficie de la puerta exterior del elemento constructivo correspondiente*	**Puerta exterior**			
A	**Muro ext. - aire ext.**	8	**100,29**	m²	*La zona de temperatura "A" es la temperatura exterior*	**Muro ext. - aire ext.**	**0,130**	**15**	**56**
B	**Muro ext. - terreno**	9	**0,00**	m²	*La zona de temperatura "B" es el Terreno*	**Muro ext. - terreno**			
A	**Techo / cubierta - Aire ext.**	10	**155,80**	m²		**Techo / cubierta - Aire ext.**	**0,132**	**-57**	**158**
B	**Solera / losa piso / forjado sanitario**	11	**139,35**	m²		**Solera / losa piso / forjado sanitario**	**0,116**		
		12	**0,00**	m²	*Las zonas de temperatura "A", "B", "P" y "X" pueden utilizarse; NO puede utilizarse la "I"*				
		13	**0,00**	m²	*Las zonas de temperatura "A", "B", "P" y "X" pueden utilizarse; NO puede utilizarse la "I"* Factor para X				
X		14	**0,00**	m²	*Zona de temperatura "X". El usuario introduce el factor de temperatura ponderado (0 < ft < 1):* **75%**				
						Puentes térmicos - resumen	Ψ [W/(mK)]		
A	**PTs ambiente exterior**	15	**0,00**	m	*Unidades en metros lineales*	**PTs ambiente exterior**			
P	**PTs perimetrales en el zócalo**	16	**0,00**	m	*Unidades en metros lineales, la zona de la temperatura "P" corresponde al perímetro (ver hoja de "Terreno")*	**PTs perimetrales en el zócalo**			
B	**Puentes térmicos P/ES**	17	**0,00**	m	*Unidades en metros lineales*	**Puentes térmicos P/ES**			
I	**Muro divisorio entre viviendas**	18	**0,00**	m²	*Sin pérdida de calor, sólo se considera para el cálculo de la carga de calefacción.*	**Muro divisorio entre viviendas**			
Total de la envolvente térmica			**414,07**	**m²**		**Promedio de la envolvente térmica**	**0,152**		

Ir a lista de componentes constructivos

Introducción de superficies

2-Ordenar: POR ID

Nr. de área	Denominación elemento constructivo	Grupo n°	Asignación al grupo	Cantidad	x (	a [m]	x	b [m]	+	Definido por el usuario [m²]	-	Restado por el usuario [m²]	-	Sustracción de las ventanas [m²]	) =	Superficie [m²]	Selección de elemento constructivo / sistema constructivo certificado	Valor-U [W/(m²K)]	Desviación respecto al norte	Ángulo de inclinación respecto a la horizontal	Orientación	Factor de reducción de sombras total	Absorción de la envolvente exterior	Emisividad exterior
	Huella proyectada del edificio	**0**	Huella proyectada del edificio		x (		x		+	**139,35**	-		)		=	0,0								
	Superficie de referencia energética	**1**	SRE (sup. de referencia energética)	**1**	x (		x		+	**117,42**	-		)		=	117,4								
	Puerta exterior	**7**	Puerta exterior		x (		x		+		-		) -		=		Puerta exterior							
1	**Losa de piso / solera_001_D**	**11**	Solera / losa piso / forjado sanitario	**1**	x (	**15,24**	x	**9,14**	+		-		) -	0,0	=	139,4	03ud-Foundation Slab	**0,116**	**270**	**180**	Hor			
2	**Pared_002_S**	**8**	Muro ext. - aire ext.	**1**	x (	**15,24**	x	**2,44**	+		-		) -	9,9	=	27,3	01ud-Exterior Wall	**0,130**	**180**	**90**	South	**0,70**	**0,60**	**0,90**
3	**Pared_003_W**	**8**	Muro ext. - aire ext.	**1**	x (	**9,14**	x	**2,44**	+		-		) -	1,9	=	20,4	01ud-Exterior Wall	**0,130**	**270**	**90**	West	**0,70**	**0,60**	**0,90**
4	**Pared_004_N**	**8**	Muro ext. - aire ext.	**1**	x (	**15,24**	x	**2,44**	+		-		) -	5,1	=	32,1	01ud-Exterior Wall	**0,130**	**0**	**90**	North	**0,70**	**0,60**	**0,90**
5	**Pared_005_E**	**8**	Muro ext. - aire ext.	**1**	x (	**9,14**	x	**2,44**	+		-		) -	1,9	=	20,4	01ud-Exterior Wall	**0,130**	**90**	**90**	East	**0,70**	**0,60**	**0,90**
6	**Techo_006_H**	**10**	Techo / cubierta - Aire ext.	**1**	x (		x		+	**54,53**	-		) -	0,0	=	54,5	02ud-Hip Roof	**0,132**	**180**	**27**	Hor	**0,70**	**0,50**	**0,90**
7	**Techo_007_H**	**10**	Techo / cubierta - Aire ext.	**1**	x (		x		+	**23,37**	-		) -	0,0	=	23,4	02ud-Hip Roof	**0,132**	**270**	**27**	Hor	**0,70**	**0,50**	**0,90**
8	**Techo_008_H**	**10**	Techo / cubierta - Aire ext.	**1**	x (		x		+	**54,53**	-		) -	0,0	=	54,5	02ud-Hip Roof	**0,132**	**0**	**27**	Hor	**0,70**	**0,50**	**0,90**
9	**Techo_009_H**	**10**	Techo / cubierta - Aire ext.	**1**	x (		x		+	**23,37**	-		) -	0,0	=	23,4	02ud-Hip Roof	**0,132**	**90**	**27**	Hor	**0,70**	**0,50**	**0,90**
10	-				x (		x		+		-		) -	0,0	=									
11	-				x (		x		+		-		) -	0,0	=									
12	-				x (		x		+		-		) -	0,0	=									
13	-				x (		x		+		-		) -	0,0	=									
14	-				x (		x		+		-		) -	0,0	=									
15	-				x (		x		+		-		) -	0,0	=									
16	-				x (		x		+		-		) -	0,0	=									
17	-				x (		x		+		-		) -	0,0	=									
18	-				x (		x		+		-		) -	0,0	=									
19	-				x (		x		+		-		) -	0,0	=									
20	-				x (		x		+		-		) -	0,0	=									
21	-				x (		x		+		-		) -	0,0	=									
22	-				x (		x		+		-		) -	0,0	=									
23	-				x (		x		+		-		) -	0,0	=									
24	-				x (		x		+		-		) -	0,0	=									
25	-				x (		x		+		-		) -	0,0	=									
26	-				x (		x		+		-		) -	0,0	=									
27	-				x (		x		+		-		) -	0,0	=									
28	-				x (		x		+		-		) -	0,0	=									
29	-				x (		x		+		-		) -	0,0	=									
30	-				x (		x		+		-		) -	0,0	=									
31	-				x (		x		+		-		) -	0,0	=									
32	-				x (		x		+		-		) -	0,0	=									
33	-				x (		x		+		-		) -	0,0	=									
34	-				x (		x		+		-		) -	0,0	=									
35	-				x (		x		+		-		) -	0,0	=									
36	-				x (		x		+		-		) -	0,0	=									

Pérdidas de calor a través del terreno

##

Sección del edificio 1

Características del terreno			
Conductividad térmica	λ	2,0	W/(mK)
Capacidad térmica	ρc	2,0	MJ/(m³K)
Profundidad de penetración periódica	δ	3,17	m

Datos climáticos			
Temp. media interior en invierno	T_i	20,0	°C
Temp. media interior en verano	T_i	25,0	°C
Temp. media superficie del terreno	$T_{ter,med}$	17,4	°C
Amplitud $T_{e,promedio}$	$T_{ter,\wedge}$	12,9	°C
Cambio de fases de $T_{e,m}$	τ	1,1	Meses
Duración del periodo de calefacción	n	4,2	Meses
Grados-hora de calefacción, exterior	G_t	43,9	kKh/a

Datos del edificio							
				Valor-U solera o losa / techo sótano	$U_{l,s,fs}$	0,118	W/(m²K)
Superficie de losa de piso / entrepiso de sótano	A	128,0	m²	PTs solera o losa / techo sótano	$\Psi_B{}^*l$		W/K
Longitud perimetral	P	47,0	m	Valor-U solera o losa / techo sótano incl. PT	$U_{l,s,fs}'$	0,118	W/(m²K)
valores característicos elem. cons. horizontal	B'	5,45	m	Espesor efectivo del piso	d_t	16,95	m

Tipo de losa de piso / solera (marcar sólo un campo)

☐ **Losa de piso / solera en contacto con el terreno**

Espesor / profundidad aislamiento perimetral	D	2,00	m	Posición del aislamiento perimetral	Horizontal	x
Espesor aislamiento perimetral	d_n	0,20	m	(marcar con una "x")	Vertical	
Conductividad térmica aislamiento perimetral	λ_{borde}	0,035	W/(mK)			

☐ **Sótano calefactado o losa de piso completamente / parcialmente bajo el nivel de terreno**

Altura pared sótano sobre rasante	z		m	Valor-U pared sótano bajo rasante del terreno	U_{sot}		W/(m²K)

☐ **Sótano no calefactado**

Altura pared sótano sobre rasante	h		m	Valor-U pared sótano sobre rasante del terreno	U_{par}		W/(m²K)
Altura pared sótano sobre rasante	z		m	Valor-U pared sótano bajo rasante del terreno	$U_{par,sot}$		W/(m²K)
Renovación de aire en sótano no calefactado	n	0,20	h^{-1}	Valor-U suelo sótano / losa de piso sótano	U_{ssot}		W/(m²K)
Volumen de aire del sótano	V		m³				

☐ **Losa de piso con cámara de aire ventilada (máx. 0.5 m por debajo de rasante)**

Valor-U losa de piso sobre cámara de aire	U_{hueco}		W/(m²K)	Sección aperturas de ventilación	εP		m²
Altura pared cámara de aire	h		m	Velocidad de viento a 10 m de altura	v	4,0	m/s
Valor-U pared cámara de aire	U_{par}		W/(m²K)	Factor de protección del viento	f_V	0,05	-

Pérdida de puente térmico adicional en el zócalo (perímetro del edificio)				Fracción estacionaria	$\Psi_{P,stat}{}^*l$		W/K
Cambio de fases	β		Meses	Cuota periódica	$\Psi_{P,harm}{}^*l$	0,000	W/K

Corrección de nivel freático						
Profundidad del nivel freático	$z_{agua\ fr}$	3,0	m	Factor de corrección agua subterránea	$G_{agua\ fr}$	-
Velocidad de flujo NF	$q_{agua\ fr}$	0,05	m/d			

Resultados temporales

Cambio de fases	β		Meses	Flujo de calor estacionario	Φ_{est}		W
Conductancia estacionaria	L_S		W/K	Flujo de calor periódico	Φ_{harm}		W
Conductancia estacionaria	L_S		W/K	Pérdidas de calor durante el periodo de calefacción	Q_{tot}		kWh
Conductancia periódica exterior	L_0		W/K				

Temperaturas del terreno mensuales para cálculo de método mensual (elemento constructivo 1)

Mes	1	2	3	4	5	6	7	8	9	10	11	12	Valor medio
Invierno													
Verano													

Temperatura de cálculo del terreno para la hoja 'Carga-C'		**Para hoja 'Carga-R'**	
Factor de reducción para hoja 'Calefacción anual'			

Resultado total (todas las secciones del edificio)

Cambio de fases	β		Meses	Flujo de calor estacionario	Φ_{est}		W
Conductancia estacionaria	L_S		W/K	Flujo de calor periódico	Φ_{harm}		W
Conductancia periódica exterior	L_{pe}		W/K	Pérdidas de calor durante el periodo de calefacción	Q_{tot}		kWh
Conductancia edificio	L_0	0,00	W/K	valores característicos elem. cons. horizontal	B'	5,45	m

Temperaturas del terreno mensuales para cálculo de método mensual (todos los elementos constructivos)

Mes	1	2	3	4	5	6	7	8	9	10	11	12	Valor medio
Invierno													
Caso verano													

Temperatura de cálculo del terreno para hoja 'Carga-C'		**Para hoja 'Carga-R'**	
Factor de reducción para hoja 'Calefacción anual'			

Componentes Casa Pasiva

#¡VALOR!

Ir a: 'SUPERFICIES'	www.passivehouse.com/component-database
Puentes térmicos (Valores-Psi)	Aparatos de ventilación
Acristalamiento	Unidades compactas
Marcos de ventana	Recuperación de calor ACS

Elementos constructivos (Valores-U)

Valores recomendados para comenzar la optimización: Valores-U muros y cubiertas | Solera / losa piso: 0,3 W/(m²K) | 0,54 W/(m²K)

		1			
ID	**Sistema constructivo**	**Elemento constructivo**	**Espesor total**	**Valor-U**	**Aisla-miento interior**
	Resumen de los elementos constructivos calculados en la hoja 'Valores-U'		m	W/(m²K)	-
01ud	**Pared exterior**	**Pared exterior**	**0,366**	**0,130**	**0**
02ud	**Cubierta inclinada**	**Cubierta inclinada**	**0,428**	**0,132**	**0**
03ud	**Solera**	**Solera**	**0,584**	**0,116**	**0**
04ud					
05ud					
06ud					
07ud					
08ud					
09ud					
10ud					

Acristalamiento			Acristalamiento
	Acristalamiento recomendado para empezar la planificación **Acristalamiento triple aislado térmicamente (¡Por favor, considere el criterio de confort!)**		
ID	**Descripción**	**Valor g**	**Valor-Ug**
			W/(m²K)
01ud	**PH Glazing**	**0,50**	**0,60**
02ud		**0,00**	**0,00**
03ud		**0,00**	**0,00**
04ud		**0,00**	**0,00**
05ud		**0,00**	**0,00**
06ud		**0,00**	**0,00**
07ud		**0,00**	**0,00**
08ud		**0,00**	**0,00**
09ud		**0,00**	**0,00**
10ud		**0,00**	**0,00**

Marcos de ventana

Marcos de ventana

		Valor U_f				Ancho del marco				Puente térmico en borde de vidrio				Puente térmico de instalación				Fachadas muro cortina:
ID	Descripción	Izquierda	Derecha	Abajo	Arriba	Izquierda	Derecha	Abajo	Arriba	$\Psi_{\text{Borde vidrio}}$ izquierda	$\Psi_{\text{Borde vidrio}}$ derecha	$\Psi_{\text{Borde vidrio}}$ abajo	$\Psi_{\text{Borde vidrio}}$ arriba	$\Psi_{\text{Instalación}}$ izquierda	$\Psi_{\text{Instalación}}$ derecha	$\Psi_{\text{Instalación}}$ abajo	$\Psi_{\text{Instalación}}$ arriba	Valor- χ_{GT} Montante
		W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/K
01ud	PH-FRAMES: average thermal quality	0,75	0,75	0,75	0,75	0,110	0,110	0,110	0,110	0,030	0,030	0,030	0,030	0,040	0,040	0,040	0,040	0,000
02ud	smartwin SLIDING_right FIXED	1,29	0,53	0,66	0,53	0,110	0,086	0,108	0,086	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
03ud	smartwin SLIDING_left SLIDING	0,81	1,29	1,08	0,84	0,085	0,110	0,117	0,092	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
04ud	smartwin F + right C_left FIXED	0,53	0,73	0,72	0,63	0,067	0,055	0,076	0,067	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
05ud	smartwin F + right C_right CASEMENT	0,73	0,71	0,93	0,71	0,055	0,067	0,076	0,067	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
06ud	smartwin F + left C_right FIXED	0,73	0,53	0,72	0,63	0,055	0,067	0,076	0,067	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
07ud	smartwin F + left C_left CASEMENT	0,71	0,73	0,93	0,71	0,067	0,055	0,076	0,067	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
08ud	smartwin SINGLE CASEMENT	0,72	0,71	0,93	0,71	0,142	0,067	0,076	0,067	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
09ud		0,00	0,00	0,00	0,00	0,000	0,000	0,000	0,000	0,030	0,030	0,030	0,030	0,000	0,000	0,000	0,000	0,000
10ud		0,00	0,00	0,00	0,00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Aparatos de ventilación con recuperación de calor

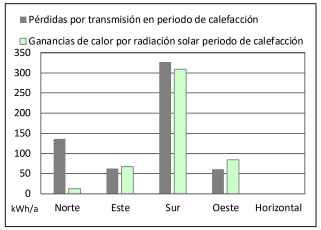
Aparatos de ventilación con recuperación de calor

	Especificaciones recomendadas para comenzar con la planificación: Protección frente a la congelación: Sí; Recuperación de humedad: Sí	75 %		0,45	Información adicional del aparato de ventilación								
ID	Descripción	Eficiencia de recuperación de calor	Eficiencia de recuperación de humedad	Eficiencia eléctrica	Rango de aplicación		Presión exterior por sección	Ajustes $\Delta p_{interno}$	Protección frente a congelación necesaria	Protección contra el ruido			Información adicional
	Área definida por el usuario	%	%	Wh/m³	m³/h	m³/h	Pa	Pa		35 dB(A)	Aire de impulsión dB(A)	Aire de extracción dB(A)	
01ud													
02ud													
03ud													
04ud													
05ud													
06ud													
07ud													
08ud													
09ud													
10ud													

Ventanas

#######

Orientación de la superficie de la ventana	Radiación global (orientaciones principales)	Sombras	Suciedad	Incidencia de radiación no vertical	Proporción de acristalamiento	Valor g	Factor de reducción para radiación solar	Superficie de ventana	Valor-U de ventana	Superficie de acristalamiento	Radiación global promedio		Pérdidas por transmisión en periodo de calefacción	Ganancias de calor por radiación solar periodo de calefacción
Valores estándar →	kWh/(m²a)	0,75	0,95	0,85				m²	W/(m2K)	m²	kWh/(m²a)		kWh/a	kWh/a
Norte	78	0,64	0,95	0,85	0,73	0,08	0,38	5,06	0,61	3,70	78	Norte	136	12
Este	234	0,60	0,95	0,85	0,64	0,50	0,31	1,86	0,76	1,19	234	Este	62	67
Sur	522	0,21	0,95	0,85	0,72	0,50	0,12	9,85	0,75	7,09	522	Sur	326	310
Oeste	243	0,62	0,95	0,85	0,74	0,50	0,37	1,86	0,74	1,38	243	Oeste	60	84
Horizontal	376	1,00	0,95	0,85	0,00	0,00	0,00	0,00	0,00	0,00	376	Horizontal	0	0
Total o valor promedio de todas las ventanas						0,38	0,23	18,63	0,71	13,35			585	473



Recomendación para $U_{W,instalada}$ [W/(m²K)]

0,90	1,07	1,17	0,49

Grados hora calefacción [kKh/a]: 43,9

Ir a lista de acristalamientos

Ir a lista de marcos de ventana

					Medidas hueco de albañilería		Instalado en	Acristalamiento	Marco	Valor g	Valor-U		Ψ Borde de vidrio	Situación de instalación valor definido por el usuario para $\Psi_{instalación}$ o '1': $\Psi_{instalación}$ de hoja 'Componentes' '0': en el caso de ventanas adjuntas					Resultados			
Cantidad	Descripción	Desviación con respecto al norte	Ángulo de inclinación respecto a la horizontal	Orientación	Anchura	Altura	Selección a partir de hoja 'Superficies'	Selección a partir de hoja 'Componentes'	Selección a partir de hoja 'Componentes'	Radiación perpendicular	Acristalamiento	Marco (pro- medio)	$\Psi_{Borde\ de\ vidrio}$ (Prom.)	Izquierda	Derecha	Abajo	Arriba	$\Psi_{Instalación}$ (Prom.)	Superficie de ventana	Superficie de vidrio	Uv instalada	Proporción de acristalamiento por ventana
		°	°		m	m		**1-Ordenar: COMO LISTA**	**1-Ordenar: COMO LISTA**	-	W/(m²K)	W/(m²K)	W/(mK)	W/(mK) o 1/0				W/(mK)	m²	m²	W/(m²K)	%
1	**Vent._001_S**	180	90	Sur	1,055	2,033	2-Pared_002_S	01ud-PH Glazing	02ud-smartwin SLIDING_right FIXED	0,50	0,60	0,83	0,030	0	1	1	1	0,000	2,1	1,58	0,74	74%
1	**Vent._002_S**	180	90	Sur	1,055	2,033	2-Pared_002_S	01ud-PH Glazing	03ud-smartwin SLIDING_left SLIDING	0,50	0,60	1,04	0,030	1	0	1	1	0,000	2,1	1,57	0,79	73%
1	**Vent._003_N**	0	90	Norte	1,016	2,032	4-Pared_004_N	0634ed03-pro Passivhausfenster - smartwin entrance	0634ed03-pro Passivhausfenster - smartwin entrance	0,00	0,34	0,78	0,005	1	1	1	1	0,040	2,1	1,55	0,58	75%
1	**Vent._004_N**	0	90	Norte	1,016	2,032	4-Pared_004_N	0634ed03-pro Passivhausfenster - smartwin entrance	0634ed03-pro Passivhausfenster - smartwin entrance	0,00	0,34	0,78	0,005	1	1	1	1	0,040	2,1	1,55	0,58	75%
1	**Vent._005_S**	180	90	Sur	0,760	1,219	2-Pared_002_S	01ud-PH Glazing	05ud-smartwin F + right C_right CASEMENT	0,50	0,60	0,77	0,030	0	1	1	1	0,000	0,9	0,69	0,75	74%
1	**Vent._006_S**	180	90	Sur	0,760	1,219	2-Pared_002_S	01ud-PH Glazing	04ud-smartwin F + right C_left FIXED	0,50	0,60	0,65	0,030	1	0	1	1	0,000	0,9	0,69	0,72	74%
1	**Vent._007_S**	180	90	Sur	0,762	1,219	2-Pared_002_S	01ud-PH Glazing	08ud-smartwin SINGLE CASEMENT	0,50	0,60	0,75	0,030	1	1	1	1	0,000	0,9	0,60	0,76	64%
1	**Vent._008_W**	270	90	Oeste	0,762	1,219	3-Pared_003_W	01ud-PH Glazing	06ud-smartwin F + left C_right FIXED	0,50	0,60	0,65	0,030	0	1	1	1	0,000	0,9	0,69	0,72	74%
1	**Vent._009_W**	270	90	Oeste	0,762	1,219	3-Pared_003_W	01ud-PH Glazing	07ud-smartwin F + left C_left CASEMENT	0,50	0,60	0,77	0,030	1	0	1	1	0,000	0,9	0,69	0,75	74%
1	**Vent._010_N**	0	90	Norte	0,762	1,219	4-Pared_004_N	01ud-PH Glazing	08ud-smartwin SINGLE CASEMENT	0,50	0,60	0,75	0,030	1	1	1	1	0,000	0,9	0,60	0,76	64%
1	**Vent._011_E**	90	90	Este	0,762	1,219	5-Pared_005_E	01ud-PH Glazing	08ud-smartwin SINGLE CASEMENT	0,50	0,60	0,75	0,030	1	1	1	1	0,000	0,9	0,60	0,76	64%
1	**Vent._012_E**	90	90	Este	0,762	1,219	5-Pared_005_E	01ud-PH Glazing	08ud-smartwin SINGLE CASEMENT	0,50	0,60	0,75	0,030	1	1	1	1	0,000	0,9	0,60	0,76	64%
1	**Vent._013_S**	180	90	Sur	0,762	1,219	2-Pared_002_S	01ud-PH Glazing	08ud-smartwin SINGLE CASEMENT	0,50	0,60	0,75	0,030	1	1	1	1	0,000	0,9	0,60	0,76	64%
1	**Vent._014_S**	180	90	Sur	0,760	1,219	2-Pared_002_S	01ud-PH Glazing	06ud-smartwin F + left C_right FIXED	0,50	0,60	0,65	0,030	0	1	1	1	0,000	0,9	0,69	0,72	74%
1	**Vent._015_S**	180	90	Sur	0,760	1,219	2-Pared_002_S	01ud-PH Glazing	07ud-smartwin F + left C_left CASEMENT	0,50	0,60	0,77	0,030	1	0	1	1	0,000	0,9	0,69	0,75	74%
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Cálculo de los factores de sombra

#¡VALOR!

Latitud geográfica: 35,47 °

Orientación	Acristala- miento superficie [m²]	Factor de reducción invierno r_v	Factor de reducción refrigeración $r_{v,1}$	Factor de reducción carga refrig. $r_{v,2}$	Carga solar [kWh/(m²$_{Acrist.}$a)]
Norte	**3,70**	**64%**	**22%**	**10%**	**16**
Este	**1,19**	**60%**	**20%**	**9%**	**36**
Sur	**7,09**	**21%**	**13%**	**6%**	**20**
Oeste	**1,38**	**62%**	**21%**	**9%**	**38**
Horizontal	**0,00**	**100%**	**100%**	**100%**	**0**

								Horizonte		Telares / Remetimientos laterales		Voladizos / Volados						Factores de reducción por sombreamiento en invierno				Factores de reducción por sombreamiento en verano				
Cantidad	Descripción	Desviación con respecto al norte	Ángulo de inclinación respecto a la horizontal	Orientación	Ancho del vidrio	Altura del vidrio	Superficie de vidrio	Altura del objeto que causa la sombra	Distancia horizontal	Profundidad de telares/remeti- mientos laterales	Distancia del borde del vidrio al telar/remetimiento	Profundidad del voladizo/volado	Distancia del borde superior del vidrio hasta voladizo/volado	Factor de reducción adicional para sombreamiento en invierno	Factor de reducción adicional para sombreamiento en verano	Factor de reducción para protección solar temporal	Regulado / Transparente	Horizonte	Telares / Remetimientos	Voladizos / Volados	**Total para la carga de calefacción**	Horizonte	Telares / Remetimientos	Voladizos / Volados	**Total para el caso de refrigeración**	**Total para la carga de refrigeración**
		[Grado]	[Grado]		w_G [m]	h_G [m]	A_{ACR} [m^2]	h_{Hori} [m]	d_{Hori} [m]	o_{Rem} [m]	d_{Rem} [m]	o_{vol} [m]	d_{vol} [m]	$r_{otro,i}$ [%]	$r_{otro,v}$ [%]	**z [%]**		r_H [%]	r_R [%]	r_V [%]	r_I [%]	r_H [%]	r_R [%]	r_V [%]	$r_{V,1}$ [%]	$r_{V,2}$ [%]
1	Vent._001_S	180	90	Sur	0,86	1,84	1,6							17%	38%	6%					17%				13%	6%
1	Vent._002_S	180	90	Sur	0,86	1,82	1,6							16%	37%	6%					16%				13%	6%
1	Vent._003_N	0	90	Norte	0,82	1,89	1,6							23%	28%						23%				28%	28%
1	Vent._004_N	0	90	Norte	0,82	1,89	1,6							41%	46%						41%				46%	46%
1	Vent._005_S	180	90	Sur	0,64	1,08	0,7							15%	34%	6%					15%				12%	5%
1	Vent._006_S	180	90	Sur	0,64	1,08	0,7							15%	34%	6%					15%				12%	5%
1	Vent._007_S	180	90	Sur	0,55	1,08	0,6							45%	42%	6%					45%				15%	7%
1	Vent._008_W	270	90	Oeste	0,64	1,08	0,7							60%	61%	6%					60%				21%	9%
1	Vent._009_W	270	90	Oeste	0,64	1,08	0,7							64%	61%	6%					64%				21%	9%
1	Vent._010_N	0	90	Norte	0,55	1,08	0,6							64%	64%	6%					64%				22%	10%
1	Vent._011_E	90	90	Este	0,55	1,08	0,6							60%	60%	6%					60%				20%	9%
1	Vent._012_E	90	90	Este	0,55	1,08	0,6							60%	60%	6%					60%				20%	9%
1	Vent._013_S	180	90	Sur	0,55	1,08	0,6							44%	42%	6%					44%				14%	6%
1	Vent._014_S	180	90	Sur	0,64	1,08	0,7							15%	34%	6%					15%				12%	5%
1	Vent._015_S	180	90	Sur	0,64	1,08	0,7							15%	34%	6%					15%				12%	5%
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Datos de ventilación

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Superficie de referencia energética A_{SRE}	m²	117		*(Hoja de cálculo 'Superficies')*
Altura de la habitación h	m	2,50	2,50	
Volumen de aire interior ventilación (A_{SRE}*h) V_V	m³	294		*('Hoja de cálculo 'Calefacción anual')*

Tipo de ventilación

Por favor seleccione	1-Vent. equilibrada PH con recuperación calor

Tasa de renovación de aire por infiltración

Coeficientes de protección al viento e y f

Coeficiente e de clase de protección de viento	Varios lados expuesto al viento	Sólo un lado expuesto al viento
Sin protección	0,10	0,03
Protección moderada	0,07	0,02
Protección alta	0,04	0,01
Coeficiente f	15	20

			P/ demanda anual	P/ periodo calefacción:	Volumen de aire neto para el ensayo de presión V_{n50}		Permeabilidad del aire q_{50}	
Coeficiente de protección de viento e			0,07	0,18				
Coeficiente de protección de viento f			15	15				
Tasa renovación aire ensayo presión	n_{50}	1/h	0,60	0,60	322	m³	0,47	m³/(hm²)

			P/ demanda anual	P/ periodo calefacción:
Exceso de aire de extracción		1/h	0,00	0,00
Tasa renovación aire por infiltración	$n_{V,Infiltración}$	1/h	0,046	0,115

Selección de los datos de la ventilación - Resultados

El PHPP ofrece dos métodos posibles para la Planificación de los caudales de aire y la elección del aparato de ventilación. Con la Planificación estándar se puede calcular las renovaciones de aire para edificios residenciales y un aparato de ventilación como máximo. En la hoja 'Ventilación ad' se pueden considerar hasta 10 aparatos de ventilación. Los caudales de aire se pueden calcular por habitación o por zonas. Favor de seleccionar aqui el método de diseño.

	Aparato de ventilación / Eficiencia de recuperación de calor		caudal diseño m³/h	Tasa de renovación renovación de aire 1/h	Exceso de aire de extracción (sist. extracción de aire) 1/h	Valor de eficiencia de RC efectiva Ap. de ventilación [-]	Recuperación de energía [-]	Potencia específica Wh/m³	Valor de eficiencia de RC efectiva del ITA [-]
x	Diseño estándar	*(Hoja de cálculo 'Ventilación', ver abajo)*							
	Múltiples unidades de ventilación, no-res	*(Hoja de cálculo 'Vent-Adicional')*							
			92	0,31	0,00	83,2%	58,0%	0,40	0,0%
						Recuperación refrigeración		Eficiencia recuperación calor ITA	
						73,2%		η^*_{ITA}	0%

Humedad interior media durante el funcionamiento en invierno

Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre
48%	51%	59%	-	-	-	-	-	-	-	61%	51%

Entrada de datos para la ventilación equilibrada

Dimensionado del sistema de ventilación con un sólo aparato de ventilación

Ocupación	m²/pers.	45				
Cantidad de personas	P	2,6				
Aire de impulsión por persona	m³/(P*h)	30				
Demanda de aire de impulsión	m³/h	79				
Habitaciones de extracción de aire		Cocina	Baño	Baño (sólo ducha)	WC	lavadero
Cantidad		1		2		1
Demanda de extracción de aire por habitación	m³/h	60	40	20	20	20
Demanda total de aire de extracción	m³/h	120				

Caudal de aire de diseño (máx.)	m³/h	120	Recomendado:	120	m³/h

Cálculo de la renovación de aire media

Tipos de operación	Horas diarias de funcionamiento h/d	Factores referenciados a Máximo	Caudal de aire m³/h	Renovación de aire 1/h
Máximo		1,00	120	0,41
Standard	24,0	0,77	92	0,31
Basic ventilation		0,54	65	0,22
Minimum		0,40	48	0,16
			Renovación de aire media (m³/h)	Tasa de renovación de aire media (1/h)
	Valor medio	0,77	92	0,31

Selección de aparato de ventilación con recuperación de calor

Situación unidad ventilación: 1-Dentro de la envolvente térmica

		Recuperación de calor RC efectiva	Humedad calor efva. RC efectiva	Específico RC efectiva [Wh/m³]	Uso [m³/h]	Protección contra la congelación
	Ir a lista de aparatos de ventilación 1-Ordenar: COMO LISTA					
Selección aparato ventilación	0680vs03-PAUL - CLIMOS F 200 (Comfort)	0,84	0,58	0,40	100 - 115	sí

Conductancia ducto de admisión	Ψ	W/(mK)	0,258
Longitud del ducto de admisión		m	0,6
Conductancia del ducto de expulsión	Ψ	W/(mK)	0,258
Longitud del ducto de expulsión		m	0,6
Temp. del cuarto de instalaciones		°C	
(Sólo introducir en el caso de que la unidad central está fuera de la envolvente térmica)			

Implementación de la protección contr	2-Elec.
Límite de temperatura [°C]	-2
Energía útil(kWh/a)	20
Temperatura interior (°C)	20
Temp. media exterior periodo calefacc	6,6
Temp. media terreno (°C)	17,4

Valor efectivo de recuperación de calor $\eta_{HR,ef}$ **83,2%**

Eficiencia del Recuperador del intercambiador geotérmico

Eficiencia del intercambiador tierra-aire (ITA)	η^*_{ITA}	
Eficiencia de recuperación de calor del ITA	η_{ITA}	0%

Cálculo secundario
Valor-Ψ del conducto de aire de impulsión o de admisión

Diámetro interior:	160	mm
Espesor del aislamiento:	80	mm
¿Reflectante?	x	Sí
		No
Conductividad térmica	0,035	W/(mK)
Caudal de aire nominal	92	m³/h
$\Delta\vartheta$	13	K
Diámetro exterior del tubo	0,160	m
Diámetro exterior	0,320	m
α–interior	6,75	W/(m²K)
α–Superficie	2,32	W/(m²K)
Valor-Ψ	**0,258**	**W/(mK)**
Diferencia de temp. Superficial	1,481	K

Cálculo secundario
Valor-Ψ del conducto de aire de expulsión o de extracción

Diámetro interior:	160	mm
Espesor del aislamiento:	80	mm
¿Reflectante?	x	Sí
		no
Conductividad térmica	0,035	W/(mK)
Caudal de aire nominal	92	m³/h
$\Delta\vartheta$	13	K
Diámetro exterior del tubo	0,160	m
Diámetro exterior	0,320	m
α–interior	6,75	W/(m²K)
α–Superficie	2,32	W/(m²K)
Valor-Ψ	**0,258**	**W/(mK)**
Diferencia de temp. Superficial	1,481	K

Demanda de calefacción (método anual)

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Temperatura interior: **20,0** °C

Tipo de edificio: **Vivienda unifamiliar aislada**

Superficie de referencia energética A_{SRE}: **117,4** m²

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Fact temp. Ft		G_t kKh/a		kWh/a	Por m² de SRE
Muro ext. - aire ext.	**A**	**100,3**	*	**0,130**	*	1,00	*	**43,9**	=	572	4,87
Muro ext. - terreno	**B**		*		*	0,40	*		=		
Techo / cubierta - Aire ext.	**A**	**155,8**	*	**0,132**	*	1,00	*	**43,9**	=	901	7,68
Solera / losa piso / forjado sanitario	**B**	**139,4**	*	**0,116**	*	0,40	*	**43,9**	=	287	2,44
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Ventanas	**A**	**18,6**	*	**0,715**	*	1,00	*	**43,9**	=	585	4,98
Puerta exterior	**A**		*		*	1,00	*		=		
Puentes térmicos exteriores(longitud en m)	**A**		*		*	1,00	*		=		0,00
Puentes térmicos perímetro (longitud en m)	**P**		*		*	0,40	*		=		0,00
Puentes térmicos piso (longitud en m)	**B**		*		*	0,40	*		=		0,00
Total de superficies de la envolvente térmica		414,1									kWh/(m²a)

Pérdidas de calor por transmisión Q_T

Total 2345 | 20,0

		A_{SRE} m²		Altura libre habitación m		m³
Sistema de ventilación:	Caudal de aire efectivo V_V	117,4	*	**2,50**	=	293,6

Rendimiento del recuperador de calor de la recuperación de calor η_{ef} **83%**

Eficiencia de recuperación de calor del intercambiador tierra-aire (ITA) η_{ITA} **0%**

	$n_{V,sist}$ 1/h		η_{HR}		$n_{V,Res}$ 1/h		1/h
Tasa de renovación de aire energéticamente efectiva n_{vent}	**0,314**	* (1 -	0,83	) +	**0,046**	=	0,099

	V_V m³		n_V 1/h		c_{aire} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Pérdidas de calor por ventilación Qvent	293,6	*	0,099	*	0,33	*	43,9	=	421	3,6

		Q_T kWh/a		Q_V kWh/a		Factor de reducción Noche y fin de semana Ahorro		kWh/a	kWh/(m²a)
Pérdidas totales de calor Q_P	(	2345	+	421	)	1,0	=	2766	**23,6**

Orientación de la superficie	Factor de reducción Compare c/ 'Ventanas'		Valor g (Radiación perp.)		Superficie m²		Radiación global kWh/(m²a)		kWh/a
Norte	**0,38**	*	**0,08**	*	**5,06**	*	**78**	=	12
Este	**0,31**	*	**0,50**	*	**1,86**	*	**234**	=	67
Sur	**0,12**	*	**0,50**	*	**9,85**	*	**522**	=	310
Oeste	**0,37**	*	**0,50**	*	**1,86**	*	**243**	=	84
Horizontal	**0,00**	*	**0,00**	*	**0,00**	*	**376**	=	0

Ganancias de calor por radiación solar Q_S

Total 473 | 4,0 kWh/(m²a)

	kh/d		Periodo calefacción anual d/a		Potencia esp. ql W/m²		A_{SRE} m²		kWh/a	kWh/(m²a)
Ganancias internas de calor (GICs) Q_I	0,024	*	**128**	*	**2,53**	*	117,4	=	911	7,8

			kWh/a	kWh/(m²a)
Calor disponible $Q_{disponible}$	Q_S + Q_I	=	1383	11,8
Relación calor disponible y pérdidas calor	Q_{disp} / Q_P	=	0,50	
Aprovechamiento efectivo de las guanacias de calor η_G	$(1 - (Q_{disp}/Q_P)5)\ /\ (1 - (Q_{disp}/Q_P)6)$	=	98%	
Ganancias de calor Q_G	η_G * Q_{Disp}	=	1361	**11,6**

			kWh/a	kWh/(m²a)
Demanda de calefacción Q_{Cal}	Q_P - Q_G	=	1404	**12**

Valor máx. permitid 15 kWh/(m²a)

¿Requerimiento cumplido? (Sí/No) **Sí**

Demanda de calefacción (método mensual)

##

La suma de los periodos de calefacción calculados mediante el método mensual se presentan en esta parte

Temperatura interior:	20	°C
Tipo de edificio:	Vivienda unifamiliar aislada	
Superficie de referencia energética A_{SRE}:	117,4	m²
Capacidad específica:	132	Wh/(m²K)

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Fact. red. Mensual		G_t kKh/a		kWh/a	Por m² de SRE
Muro ext. - aire ext.	A	100,3	*	0,130	*	1,00	*	53	=	686	5,84
Muro ext. - terreno	B		*		*	1,00	*		=		
Techo / cubierta - Aire ext.	A	155,8	*	0,132	*	1,00	*	53	=	1080	9,20
Solera / losa piso / forjado sanitario	B	139,4	*	0,116	*	1,00	*	19	=	309	2,63
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Ventanas	A	18,6	*	0,715	*	1,00	*	53	=	701	5,97
Puerta exterior	A		*		*	1,00	*		=		
Puentes térmicos exteriores(longitud en m)	A		*		*	1,00	*		=		0,00
Puentes térmicos perímetro (longitud en m)	P		*		*	1,00	*		=		0,00
Puentes térmicos piso (longitud en m)	B		*		*	1,00	*		=		0,00
											kWh/(m²a)
Pérdidas de calor por transmisión QT									Total	2776	23,6

		A_{SRE} m²		Altura libre habitación m		m³
Caudal de aire efectivo V_v		117	*	2,50	=	294

	$n_{V,sist}$ 1/h		η^*_{ITA}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
Renovación de aire efectiva exterior $n_{ventilación,efectiva}$	0,314	*(1-	0%	)*(1-	0,83	)+	0,046	=	0,099
Renovación de aire efectiva terreno $n_{ventilación,terreno}$	0,314	*	0%	*(1-	0,83	)		=	0,000

	V_V m³		$n_{V,equi,frac}$ 1/h		c_{aire} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Pérdidas de ventilación, exterior $Q_{Vent,e}$	294	*	0,099	*	0,33	*	53	=	504	4,3
Pérdidas de ventilación, terreno $Q_{Vent,ter}$	294	*	0,000	*	0,33	*	10	=	0	0,0
Pérdidas de calor ventilación Q_{Vent}								Total	504	4,3

		Q_T kWh/a		Q_V kWh/a			Factor de reducción Noche y fin de semana ahorro		kWh/a	kWh/(m²a)
Pérdidas totales de calor Q_P	(	2776	+	504	)	*	1,0	=	3280	**27,9**

Orientación de la superficie	Factor de reducción ver hoja 'Ventanas'		Valor g (Radiación perpendicular)		Superficie m²		Radiación global kWh/(m²a)		kWh/a	
Norte	0,38	*	0,08	*	5,1	*	101	=	15	
Este	0,31	*	0,50	*	1,9	*	300	=	86	
Sur	0,12	*	0,50	*	9,9	*	641	=	380	
Oeste	0,37	*	0,50	*	1,9	*	310	=	107	
Horizontal	0,00	*	0,00	*	0,0	*	485	=	0	
Total superficies opacas									269	
										kWh/(m²a)
Ganancias de calor por radiación solar Q_S								Total	858	7,3

	kh/d		Duración periodo calefacción d/a		Potencia esp. ql W/m²		A_{SRE} m²		kWh/a	kWh/(m²a)
Ganancias internas de calor Q_I	0,024	*	151	*	2,5	*	117,4	=	1075	9,2

			kWh/a	kWh/(m²a)
Calor disponible $Q_{disponible}$	Q_S + Q_I	=	1933	16,5
Relación entre el calor disponible y las pérdidas de ca	Q_{disp} / Q_P	=	0,59	
Aprovechamiento efectivo de las guanacias de calor η_G		=	100%	
			kWh/a	kWh/(m²a)
Ganancias de calor Q_G	η_G * Q_{Disp}	=	1924	**16,4**

			kWh/a	kWh/(m²a)
Demanda de calefacción Q_{Cal}	Q_P - Q_G	=	1356	**12**

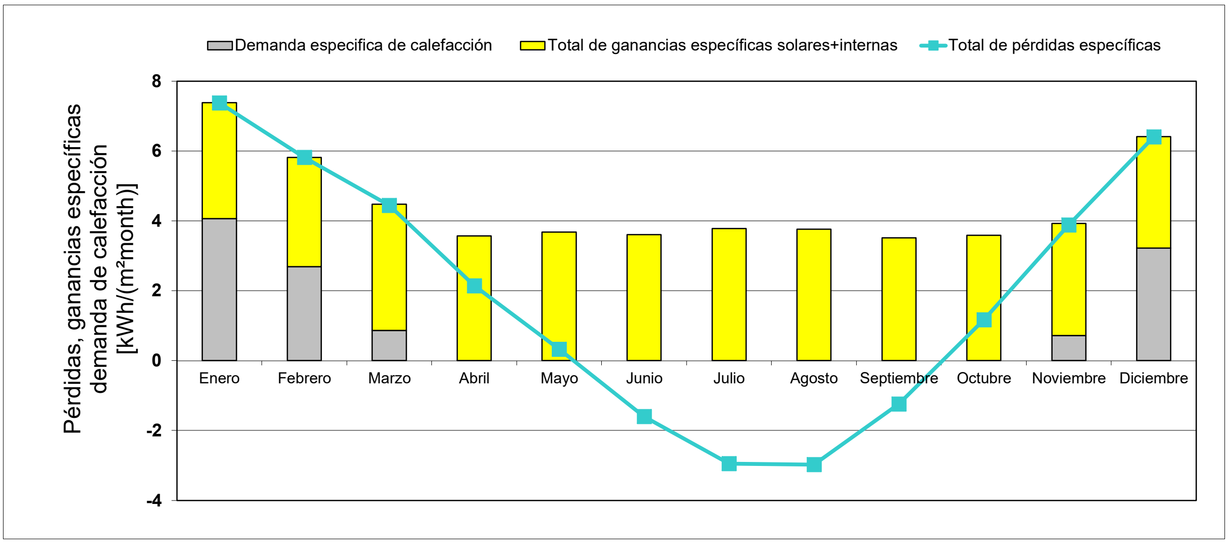
	kWh/(m²*a)		(Si/No)
Valor máx. permitido	15	**¿Requerimiento cumplido?**	**Sí**

Demanda de calefacción (método mensual)

#¡VALOR!

Temperatura interior: **20** °C
Tipo de edificio: **Vivienda unifamiliar aislada**
Superficie de referencia energética A_{SRE}: **117** m²

	Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre	Año	
Grados-hora de calefacción, ext	14,0	10,6	7,6	3,2	-0,2	-3,6	-5,9	-5,6	-2,0	2,7	7,9	12,5	41	kKh
Grados-hora de calefacción, ter	4,7	5,2	5,8	4,6	2,9	0,8	-1,0	-2,0	-2,0	-1,1	0,7	2,8	21	kKh
Pérdidas hacia el exterior	792	599	429	178	-9	-201	-330	-316	-113	155	445	707	2335	kWh
Pérdidas hacia el terreno	75	84	93	74	48	13	-16	-33	-33	-17	11	46	345	kWh
Total de pérdidas específicas	7,4	5,8	4,4	2,1	0,3	-1,6	-2,9	-3,0	-1,2	1,2	3,9	6,4	22,8	kWh/m²
Ganancias solares - norte	3	3	5	5	7	8	7	6	5	4	3	3	57	kWh
Ganancias solares - este	16	17	24	27	29	31	32	31	25	22	16	14	282	kWh
Ganancias solares - sur	82	73	75	59	50	44	48	58	66	82	75	75	787	kWh
Ganancias solares - oeste	19	22	29	35	38	37	41	38	30	27	20	17	353	kWh
Ganancias solares - horizontal	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Ganancias solares - opaco	50	53	72	80	88	91	96	89	74	66	50	45	851	kWh
Ganancias internas de calor (GI	221	199	221	214	221	214	221	221	214	221	214	221	2598	kWh
Total de ganancias específicas s	3,3	3,1	3,6	3,6	3,7	3,6	3,8	3,8	3,5	3,6	3,2	3,2	42,0	kWh/m²
Grado de aprovechamiento	100%	100%	99%	60%	9%	100%	100%	100%	100%	33%	99%	100%	27%	
Demanda de calefacción	477	315	102	0	0	0	0	0	0	0	84	378	1356	kWh
Demanda especifica de calefac	**4,1**	**2,7**	**0,9**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,7**	**3,2**	**11,5**	kWh/m²



Demanda de calefacción: comparación

Método mensual	*('Calefacción')*	**1356**	**kWh/a**	**11,5**	**kWh/(m²a) referencia a superficie de referencia energética de acuerdo a PHPP**
Método anual	*('Calefacción anual')*	**1404**	**kWh/a**	**12,0**	**kWh/(m²a) referencia a superficie de referencia energética de acuerdo a PHPP**
		#¡REF!	**kWh/a**	**#¡REF!**	

Carga de calefacción

##

Temperatura interior:	20	°C
Tipo de edificio:	Vivienda unifamiliar aislada	
Superficie de referencia energética A_{SRE}:	117,4	m²

	Temperatura de cálculo		Radiación: Norte	Este	Sur	Oeste	Horizontal	
Situación meteorológica 1:	-8,9	°C	35	35	40	35	50	W/m²
Situación meteorológica 2:	-6,2	°C	30	30	30	30	40	W/m²
Temp. del terreno considerada	12,2	°C						

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Factor Siempre 1 (excepto "X")		Dif. de temperatura 1 K		Dif. de temperatura 2 K		P_T 1 W		P_T 2 W
Muro ext. - aire ext.	A	100,3	*	0,130	*	1,00	*	28,9	o bien	26,2	=	376	o bien	341
Muro ext. - terreno	B		*		*	1,00	*	7,8	o bien	7,8	=		o bien	
Techo / cubierta - Aire ext.	A	155,8	*	0,132	*	1,00	*	28,9	o bien	26,2	=	592	o bien	537
Solera / losa piso / forjado sanitario	B	139,4	*	0,116	*	1,00	*	7,8	o bien	7,8	=	126	o bien	126
	A		*		*	1,00	*	28,9	o bien	26,2	=		o bien	
	A		*		*	1,00	*	28,9	o bien	26,2	=		o bien	
	X		*		*	0,75	*	28,9	o bien	26,2	=		o bien	
Ventanas	A	18,6	*	0,715	*	1,00	*	28,9	o bien	26,2	=	384	o bien	349
Puerta exterior	A		*		*	1,00	*	28,9	o bien	26,2	=		o bien	
Puentes térmicos exteriores(longitud en m)	A		*		*	1,00	*	28,9	o bien	26,2	=		o bien	
Puentes térmicos perímetro (longitud en m)	P		*		*	1,00	*	7,8	o bien	7,8	=		o bien	
Puentes térmicos piso (longitud en m)	B		*		*	1,00	*	7,8	o bien	7,8	=		o bien	
Muro divisorio entre viviendas	I		*		*	1,00	*	3,0	o bien	3,0	=		o bien	

Carga de calor por transmisión P_T

Total = 1479 o bien 1353

Sistema de ventilación:

	A_{SRE} m²		Altura libre de la habitación m		m³
Caudal de aire efectivo V_V	117,4	*	2,50	=	294

					η_{ITA} 1		η_{ITA} 2
Eficiencia del recuperador de calor del intercambiador de calor η_{HR}	83%	eficiencia del ITA	0%	eficiencia del ITA	0%	o bien	0%

	$n_{V,est}$ (carga de calefacción) 1/h		$n_{V,sist}$ 1/h		Φ_{RC}		Φ_{RC}		1/h		1/h
Tasa de renovación de aire energéticamente efectiva n_{vent}	0,115	+	0,314	*(1-	0,83	o bien	0,83	) =	0,168	o bien	0,168

Carga de calor ventilación P_{Vent}

V_V m³		n_V 1/h		n_V 1/h		c_{aire} Wh/(m³K)		Dif. de temperatura 1 K		Dif. de temperatura 2 K		P_P 1 W		P_P 2 W
293,6	*	0,168	o bien	0,168	*	0,33	*	28,9	o bien	26,2	=	469	o bien	426

Total de cargas de calor P_P

		P_P 1 W		P_P 2 W
$P_T + P_{Vent}$	=	**1948**	o bien	**1779**

Orientación de la superficie	Superficie m²		Valor g (Radiación perpendicular)		Factor de reducción Compare hoja 'Ventanas')		Radiación 1 W/m²		Radiación 2 W/m²		P_T 1 W		P_T 2 W
Norte	5,1	*	0,1	*	0,38	*	35	o bien	30	=	5	o bien	5
Este	1,9	*	0,5	*	0,31	*	35	o bien	30	=	10	o bien	9
Sur	9,9	*	0,5	*	0,12	*	40	o bien	30	=	24	o bien	18
Oeste	1,9	*	0,5	*	0,37	*	35	o bien	30	=	12	o bien	10
Horizontal	0,0	*	0,0	*	0,40	*	50	o bien	40	=	0	o bien	0

Cargas térmicas solares P_S

Total = 51 o bien 41

Carga interna de calor P_I

Potencia específica W/m²		A_{SRE} m²		P_I 1 W		P_I 2 W
2,0	*	117	=	238	o bien	238

Cargas térmicas (ganancias) P_G

		P_G 1 W		P_G 2 W
$P_{Acum} + P_I$	=	**289**	o bien	**279**

$P_P - P_G$ = 1659 o bien 1500

Carga de calefacción P_{Cal}

= **1659** **W**

Carga de calefacción específica PH / A_{TFA}

= **14,1** **W/m²**

					°C	°C
Introducción temp. máx. aire impulsión	52	°C				
Temp. máx. aire impulsión $\vartheta_{admis,máx}$	52	°C	Temp. del aire de impulsión sin aporte de calor a	$\vartheta_{admis,min}$	15,2	15,6

Para comparar: carga máx. de calor trasportable a través del aire impulsión $P_{Impuls;Max:}$

= **1122** W específico: 9,6 W/m²

(Sí/No)

¿Calefactable a través del aire de impulsión? **No**

-

Ventilación en verano

Casa Pasiva con PHPP Versión 9.6a

##

			Tipo de edificio:	Vivienda unifamiliar aislada	
Volumen del edificio:	294	m³	Eficiencia en la recuperación de calor:	73%	
Humedad absoluta máxima interior:	12	g/kg	Eficiencia de recuperación de calor:	58%	
Fuentes internas de humedad:	100	g/(P*h)	Eficiencia intercambiador de calor tierra-aire:	0%	

Resultados refrigeración pasiva				**Resultado refrigeración activa**		
Frecuencia de sobrecalentamiento:	25,2%		al límite de sobrecal: ϑ_{max} = 25 °C	Demanda de refrigeración útil:	10,6	kWh/(m²a)
Humedad máxima:	16,2	g/kg		Demanda de deshumidificación:	4,6	kWh/(m²a)
Frecuencia de humedad superada:	25,2%			Frecuencia de humedad superada:	0,2%	

Ventilación básica en el verano para asegurar la calidad de aire suficiente

Renov. aire sist. ventilación c/aire impulsión	0,45	1/h	HRV/ERV en verano (marcar sólo un campo con 'x')	
			Ninguna	
			Bypass automático, controlado por diferencia de temperatura	
			Bypass automático, controlado por diferencia entálpica	x
			Siempre	
Renov. aire sist. extracción de aire:		1/h		
			Consumo energético esp. (para sist.extracción de aire)	0,20 Wh/m³
Renovación de aire mediante ventanas:	0,00	1/h		

Renovación de aire efectiva

	$n_{V,sist}$ 1/h		η^*_{ITA}		η_{HR}		$n_{V,equi,frac}$ 1/h
exterior $n_{V,e}$	0,450	*(1-	0%	)*(1-	0,73	) =	0,121
sin RC	0,450	*(1-	0%	)		=	0,450
Terreno nL,g	0,450	*	0%	*(1-	0,73	) =	0,000
sin RC	0,450	*	0%			=	0,000

Valor de referencia ventilación

	V_V m³		$n_{V,equi,frac}$ 1/h		c_{aire} Wh/(m³K)			
exterior $H_{V,e}$	294	*	0,121	*	0,33	=	11,7	W/K
sin RC	294	*	0,450	*	0,33	=	43,6	W/K
Terreno $H_{V,g}$	294	*	0,000	*	0,33	=	0,0	W/K
sin RC	294	*	0,000	*	0,33	=	0,0	W/K
Infiltración, ventana, sist. extracción	294	*	0,046	*	0,33	=	4,5	W/K

Ventilación adicional en verano para refrigeración

Regulación de la ventilación adicional

Temperatura interior mínima permitida 22,0 °C

Tipo de ventilación adicional

Ventilación nocturna manual (mediante ventanas)	Valor de ventilación nocturna	1,25	1/h		
	Renovación de aire correspondiente		1/h	Regulable según (marcar con una 'x')	
mecánico, automático	durante el funcionamiento, además de cambio de aire básico			Dif. temperatura	
Ventilación controlada	Consumo energético específico		Wh/m³	Dif. humedad	x

Verano: refrigeración pasiva

##

Tipo de edificio: **Vivienda unifamiliar aislada**
Límite de sobrecalentamiento: **25** °C
Humedad nominal: **12** g/kg
Capacidad específica: **132** Wh/(m²K)

Superficie de referencia energética A_{SRE}: **117,4** m²
Volumen del edificio: **294** m³
Fuentes internas de humedad: **2,2** g/(m²h)

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Factor de reducción $f_{T,Verano}$		H_{Ver} Conductancia térmica
Muro ext. - aire ext.	**A**	**100,3**	*	**0,130**	*	1,00	=	13,0
Muro ext. - terreno	**B**		*		*	1,00	=	
Techo / cubierta - Aire ext.	**A**	**155,8**	*	**0,132**	*	1,00	=	20,5
Solera / losa piso / forjado sanitaric	**B**	**139,4**	*	**0,116**	*	1,00	=	16,2
	A		*		*	1,00	=	
	A		*		*	1,00	=	
	X		*		*	0,75	=	
Ventanas	**A**	**18,6**	*	**0,715**	*	1,00	=	13,3
Puerta exterior	**A**		*		*	1,00	=	
Puentes térmicos exteriores(longitu	**A**		*		*	1,00	=	
Puentes térmicos perímetro (longitu	**P**		*		*	1,00	=	
Puentes térmicos piso (longitud en	**B**		*		*	1,00	=	

Transmisión de calor por conducción hacia el exterior $H_{T,e}$ 46,9 W/K

Transmisión de calor por conducción hacia el terreno $H_{T,t}$ 16,2 W/K

Ventilación verano

De hoja 'Ventilación-V'

Valor referencia aparato vent.		
exterior $H_{V,e}$	**11,7**	W/K
sin RC	**43,6**	W/K
Terreno HV,g	**0,0**	W/K
sin RC	**0,0**	W/K
Valor referencia vent., otros		
Exterior	**4,5**	W/K

Parámetro de ventilación		
Fluctuación diaria de la temperatura en verano	**12,6**	K
Temperatura interior mínima permitida	**22,0**	°C
Capacidad térmica del aire	0,33	Wh/(m³K)
Renovación de aire de impulsión	**0,45**	1/h
Renovación de aire exterior	**0,05**	1/h
Renovación aire p/ ventilación nocturna ventanas, manual @ 1K	**1,25**	1/h
Renovación de aire p/ ventilación mecánica controlada	**0,00**	1/h
Consumo energético específico para:	**0,00**	Wh/m³
η_{HR}	**73%**	
η_{ERV}	**58%**	
η^*_{ITA}	**0%**	

Regulación de la ventilación en verano	HRV/ERV
Ninguno	
Regulable según temperatura	
Regulable según entalpía	**x**
Siempre	
	Ventilación adicional
Regulable según temperatura	
Regulable según humedad	**x**

Orientación de la superficie	Factor por ángulo Verano		Factor de reducción sombras Verano		Factor de Suciedad		Superficie (Radiación perpendicular)		Superficie m²		Proporción		**Apertura** m²
Norte	0,9	*	**0,10**	*	**0,95**	*	**0,08**	*	**5,1**	*	**73%**	=	0,0
Este	0,9	*	**0,09**	*	**0,95**	*	**0,50**	*	**1,9**	*	**64%**	=	0,0
Sur	0,9	*	**0,06**	*	**0,95**	*	**0,50**	*	**9,9**	*	**72%**	=	0,2
Oeste	0,9	*	**0,09**	*	**0,95**	*	**0,50**	*	**1,9**	*	**74%**	=	0,1
Horizontal	0,9	*	**1,00**	*	**0,95**	*	**0,00**	*	**0,0**	*	**0%**	=	0,0
Total superficies opacas													**0,6**

Apertura solar Total 0,9 — 0,01 m²/m²

	Potencia específica q_I W/m²		A_{SRE} m²		W	W/m²
Ganancias internas de calor (GICs) Q_I	**2,6**	*	117	=	302	2,6

Frecuencia de sobrecalentamiento $h_{\vartheta \geq \vartheta máx}$ **25,2%** **en base al límite establecido $\vartheta_{máx}$ = 25 °C**

Cuando la "frecuencia sobre 25°C" rebasa el 10%, son necesarias otras medidas de protección contra calor en el verano.

Fluctuación diaria de temperatura interior

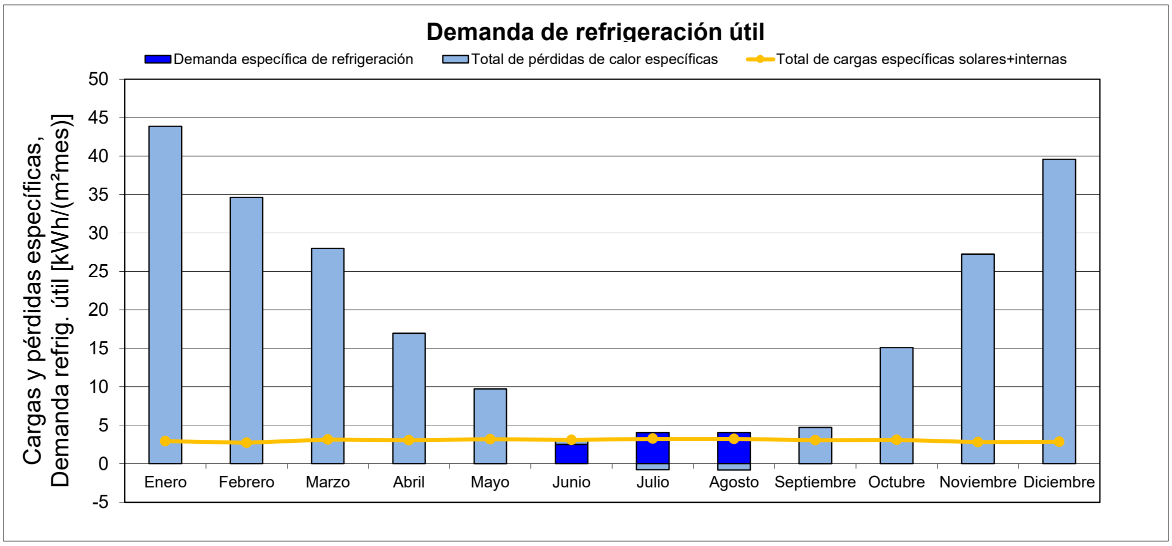
	Transmisión kWh/d		Ventilación kWh/d		Carga solar kWh/d		1/k		Capacidad específica Wh/(m²K)		A_{SRE} m²		
(	7,1	+	10,6	+	5,1	) *	1000	/ (	132	*	117	) =	**1,5** K

Refrigeración: Demanda específica refrigeración útil

#¡VALOR!

Temperatura interior: **25** °C
Tipo de edificio: **Vivienda unifamiliar aislada**
Superficie de referencia energética A_{SRE}: **117** m²

	Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre	Año	
Grados-hora de calefacción, exterio	18,0	14,2	11,5	6,9	3,7	0,1	-2,0	-1,7	1,7	6,6	11,7	16,5	87	kKh
Grados-hora de calefacción, terreno	8,4	8,5	9,5	8,2	6,7	4,4	2,7	1,7	1,6	2,7	4,3	6,5	65	kKh
Pérdidas hacia el exterior	1635	1289	1040	614	316	-1	-138	-122	127	577	1048	1493	7876	kWh
Pérdidas hacia el terreno	135	138	153	132	108	72	44	27	26	43	70	106	1054	kWh
Pérdidas ventilación en verano	3379	2638	2092	1242	716	0	0	0	397	1149	2083	3050	16748	kWh
Total de pérdidas de calor específic	43,8	34,6	28,0	16,9	9,7	0,6	-0,8	-0,8	4,7	15,1	27,3	39,6	218,7	kWh/m²
Cargas solares norte	1	1	2	2	3	3	3	2	2	1	1	1	21	kWh
Cargas solares este	6	6	9	10	10	11	11	11	9	8	6	5	102	kWh
Cargas solares sur	53	47	48	38	32	28	31	37	43	53	49	49	509	kWh
Cargas solares oeste	7	8	10	12	14	13	14	13	11	10	7	6	125	kWh
Cargas solares horizontales	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Cargas solares elementos opacos	50	53	72	80	88	91	96	89	74	66	50	45	851	kWh
Ganancias internas de calor (GIC)	225	203	225	218	225	218	225	225	218	225	218	225	2647	kWh
Total de cargas específicas solares+	2,9	2,7	3,1	3,1	3,2	3,1	3,2	3,2	3,0	3,1	2,8	2,8	36,2	kWh/m²
Grado de aprovechamiento de pérd	7%	8%	11%	18%	33%	100%	100%	100%	64%	21%	10%	7%	12%	
Demanda total de refrigeración	0	0	0	0	0	294	474	473	2	0	0	0	1243	kWh
Demanda específica de refrigeració	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**2,5**	**4,0**	**4,0**	**0,0**	**0,0**	**0,0**	**0,0**	**10,6**	kWh/m²
Demanda específica de deshumidifi	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**1,4**	**1,7**	**1,5**	**0,0**	**0,0**	**0,0**	**0,0**	**4,6**	kWh/m²
Proporción sensible	100%	100%	100%	100%	100%	65%	70%	73%	100%	100%	100%	100%	70%	



Refrigeración: Demanda específica refrigeración útil

##

La suma de los periodos de refrigeración calculados mediante el método mensual se presentan en esta parte

Tipo de edificio:	Vivienda unifamiliar aislada		Superficie de referencia energética A_{SRE}:	117,4	m²
Temperatura interior verano:	25	°C	Volumen del edificio:	294	m³
Humedad nominal:	12	g/kg	Fuentes internas de humedad:	2,2	g/(m²h)
Capacidad específica:	132	Wh/(m²K)			

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Factor de		G_t kKh/a		kWh/a	Por m² de SRE
Muro ext. - aire ext.	A	100,3	*	0,130	*	1,00	*	-2	=	-25	-0,21
Muro ext. - terreno	B		*		*	1,00	*		=		
Techo / cubierta - Aire ext.	A	155,8	*	0,132	*	1,00	*	-2	=	-39	-0,33
Solera / losa piso / forjado sanitario	B	139,4	*	0,116	*	1,00	*	10	=	169	1,44
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
	X		*		*	0,75	*		=		
Ventanas	A	18,6	*	0,715	*	1,00	*	-2	=	-25	-0,21
Puerta exterior	A		*		*	1,00	*		=		
Puentes térmicos exteriores(longitud en m)	A		*		*	1,00	*		=		0,00
Puentes térmicos perímetro (longitud en m)	P		*		*	1,00	*		=		0,00
Puentes térmicos piso (longitud en m)	B		*		*	1,00	*		=		0,00
Pérdidas de calor por transmisión Q_T (negativo= cargas de calor)									Total	80	kWh/(m²a) 0,7

Ventilación verano

De hoja 'Ventilación-V'

Valores conductancia ap. de ventilación

exterior $H_{V,e}$	11,7	W/K
sin RC	43,6	W/K
Terreno HV,g	0,0	W/K
sin RC	0,0	W/K

Valor de referencia de la ventilación, otros

Exterior	4,5	W/K

Parámetros de la ventilación

Fluctuación diaria de la temperatura en verano	12,6	K
Temperatura interior mínima permitida	22,0	°C
Capacidad térmica aire	0,33	Wh/(m³K)
Renovación de aire de impulsión	0,45	1/h
Intercambios de aire exterior	0,05	1/h
Renov. aire p/ ventilación noct. ventanas, manual @ 1K	1,25	1/h
Renovación aire ventilación mecánica controlada	0,00	1/h
Consumo energético específico para:	0,00	Wh/m³
η_{HR}	73%	
η_{ERV}	58%	
η^*_{ITA}	0%	

Regulación de la ventilación en verano

	RC/RH
Ninguno	
Regulable según temp.	
Regulable según entalpía	x
Siempre	
	Ventilación adicional
Regulable según temp.	
Regulable según humeda	x

Renovación higiénica del aire	$n_{V,sist}$ 1/h		η^*_{ITA}		η_{HR} (Consideración de bypass)		$n_{V,Rest}$ 1/h		$n_{V,equi,frac}$ 1/h
Renovación de aire efectiva exterior $n_{ventilación,efectiva}$	0,450	*(1-	0%	)*(1-	0,55	)+	0,046	=	0,248
Renovación de aire efectiva terreno $n_{ventilación,terreno}$	0,450	*	0%	*(1-	0,55	)		=	0,000

	V_V m³		$n_{V,equi,frac}$ 1/h		c_{aire} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Pérdidas ventilación, ext. $Q_{Vent,e}$	294	*	0,248	*	0,33	*	-2	=	-46	-0,4
Pérdidas ventilación, terreno $Q_{Vent,ter}$	294	*	0,000	*	0,33	*	0	=	0	0,0
Pérdidas ventilación adicional verano	294	*	0,262	*	0,33	*	16	=	397	3,4
Pérdidas de calor ventilación Q_{Vent}								Total	351	3,0

	Q_T kWh/a		Q_V kWh/a		kWh/a	kWh/(m²a)
Pérdidas totales de calor Q_P	80	+	351	=	431	**3,7**

Orientación de la superficie	Factor de reducción		Valor g (Radiación perpendicular)		Superficie m²		Radiación global kWh/(m²a)		kWh/a	
Norte	0,14	*	0,08	*	5,1	*	166	=	9	
Este	0,11	*	0,50	*	1,9	*	411	=	43	
Sur	0,08	*	0,50	*	9,9	*	363	=	139	
Oeste	0,13	*	0,50	*	1,9	*	422	=	52	
Horizontal	0,40	*	0,00	*	0,0	*	762	=	0	
Total superficies opacas									349	
Ganancias de calor por radiación solar Q_S								Total	592	kWh/(m²a) 5,0

	kh/d		Duración del periodo de refrigeración d/a		Potencia específica q_I W/m²		A_{SRE} m²		kWh/a	kWh/(m²a)
Ganancias internas de calor Q_I	0,024	*	122	*	2,6	*	117,4	=	885	7,5

			kWh/a	kWh/(m²a)
Total de cargas de calor Q_{disp}	Q_S + Q_I	=	1477	**12,6**

	Relación entre pérdidas y calor disponible Q_P / Q_{Disp}	=	0,29	
	Aprovechamiento efectivo de las pérdidas de calor η_{aprov}	=	54%	
			kWh/a	kWh/(m²a)
Pérdidas de calor aprovechables $Q_{P,aprov}$	η_G * Q_P	=	234	**2,0**
			kWh/a	kWh/(m²a)
Demanda de refrigeración Q_{REF}	Q_G - $Q_{P,aprov}$	=	1243	**11**

	kWh/(m²*a)		(Sí/No)
Valor máx. recomendado	15	**¿Requerimiento cumplido?**	**Sí**

Aparatos de refrigeración

#

Tipo de edificio:	Vivienda unifamiliar aislada		Sup. referencia energética A_{SRE}:	117,4	m²
Temperatura interior verano:	25,0	°C	Refrigeración mecánica:	x	
Humedad nominal:	12,0	g/kg	Intercambio de aire por el sistema de ventilación con aire de impulsión:	0,5	
Fuentes internas de humedad:	2,2	g/(m²h)			

☐ **Refrigeración a través del aire de impulsión**

Marcar, si procede

Funcionamiento de ciclo operativo (marcar con 'x')		
Capacidad de refrigeración máx. (sensible + latente)		kW
Reducción de temperatura bulbo seco	0,0	K
Relación de eficiencia energética estacionaria		

☒ **Refrigeración del aire en circulación**

Marcar, si procede

Funcionamiento de ciclo operativo (marcar con 'x')		
Capacidad de refrigeración máx. (sensible + latente)	8,5	kW
Volumen de aire en potencia nominal	1440,0	m³/h
Reducción de temperatura bulbo seco	17,4	K
Volumen de aire variable (marque con 'x' si aplica)	x	
Relación de eficiencia energética estacionaria	8,0	

☐ **Deshumidificación adicional**

Marcar, si procede

Volumen de aire variable (marque con 'x' si aplica)	
Relación de eficiencia energética estacionaria	

☐ **Refrigeración mediante superficies**

Marcar, si procede

Relación de eficiencia energética estacionaria	

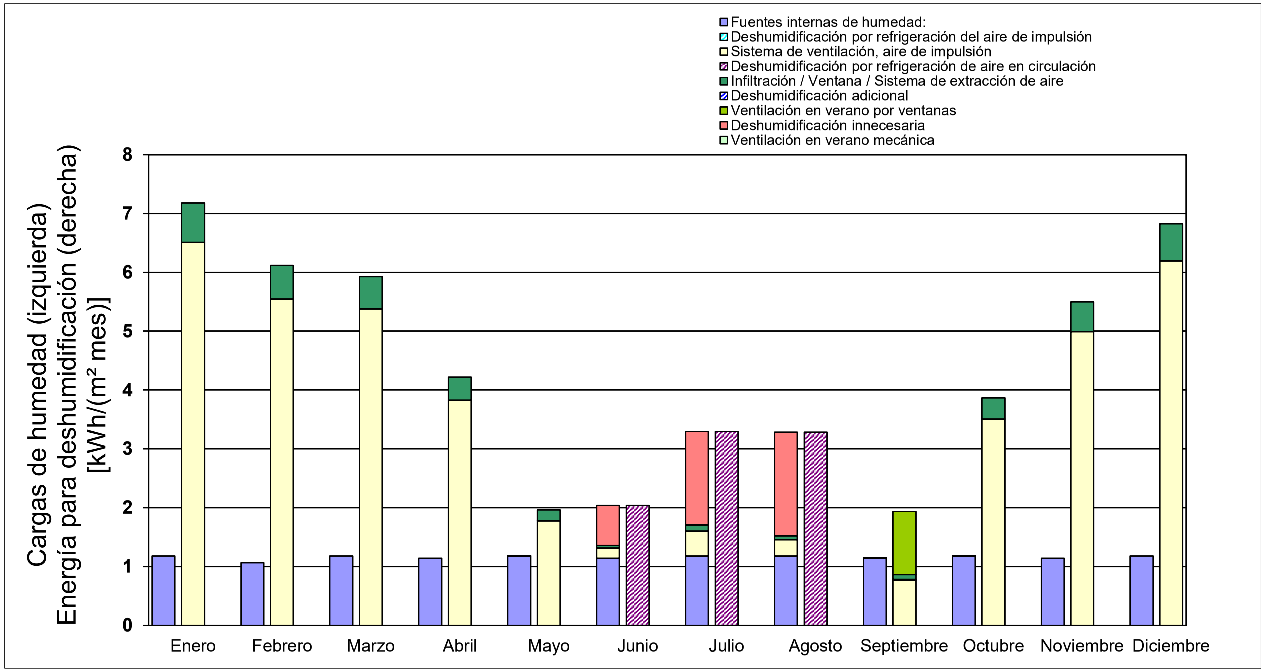
		Sensible kWh/(m²a)		Latente kWh/(m²a)		COP		Demanda electricidad kWh/(m²a)	Proporción sensible
Total refrigeración útil		10,6		4,6					70%
Contribución a la refrigeración por:									
Refrigeración a través del aire de impulsión	(		+		) /	0,0	=		
Refrigeración del aire en circulación	(	10,6	+	8,6	) /	8,0	=	2,4	55%
Deshumidificación					/		=		0%
Potencia restante refrigeración mediante superficies					/	0,0	=		100%
Distribución red de refrigeración					/	8,0	=		100%
Total	(	**10,6**	+	**8,6**	) /	8,0	=	**2,4**	55%
Demanda no cubierta		0,0		0,0		**¿Demanda de refrigeración cubierta?**			(Sí/No) **Sí**

Aparatos de refrigeración

#¡VALOR!

Cargas de humedad y eliminación de la humedad

	Enero	Febrero	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre	Año	
Fuentes internas de humedad:	1,2	1,1	1,2	1,1	1,2	1,1	1,2	1,2	1,1	1,2	1,1	1,2	14	kWh/m²
Infiltración / Ventana / Sistema de extracció	-0,7	-0,6	-0,6	-0,4	-0,2	0,0	0,1	0,1	-0,1	-0,4	-0,5	-0,6	-4	kWh/m²
Sistema de ventilación, aire de impulsión	-6,5	-5,5	-5,4	-3,8	-1,8	0,2	0,4	0,3	-0,8	-3,5	-5,0	-6,2	-38	kWh/m²
Ventilación en verano por ventanas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,1	0,0	0,0	0,0	-1	kWh/m²
Ventilación en verano mecánica	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	kWh/m²
Cargas de humedad totales	0,0	0,0	0,0	0,0	0,0	1,4	1,7	1,5	0,0	0,0	0,0	0,0	5	kWh/m²
Deshumidificación por refrigeración del aire	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	kWh/m²
Deshumidificación por refrigeración de aire	0,0	0,0	0,0	0,0	0,0	2,0	3,3	3,3	0,0	0,0	0,0	0,0	9	kWh/m²
Deshumidificación adicional	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	kWh/m²
Deshumidificación total	0,0	0,0	0,0	0,0	0,0	2,0	3,3	3,3	0,0	0,0	0,0	0,0	9	
Deshumidificación innecesaria	0,0	0,0	0,0	0,0	0,0	0,7	1,6	1,8	0,0	0,0	0,0	0,0	4	kWh/m²
Falta deshumidificación	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	kWh/m²



Carga-R

#

Tipo de edificio:	Vivienda unifamiliar aislada	Superficie de referencia energética A_{SRE}:	117,4	m²	Capacidad esp.:	132	Wh/(m²
		Volumen del edificio:	294	m³	Humedad nominal:	12,0	g/kg
		Temperatura interior:	25	°C	Fuentes internas de humedad:	2,2	g/(m²h)

Temperatura:	Aire exterior		Punto rocío			Cielo	
Clima 1:	33,6	°C	21,5	°C		20,2	°C
Clima 2:	33,6	°C	21,5	°C		21,5	°C
Temp. del terreno considerada	22,9	°C			ITA	17,4	°C

Radiación:	Norte	Este	Sur	Oeste	Horizontal	
	90	190	170	180	350	W/m²
	90	190	170	180	350	W/m²

Elemento constructivo	Zona de temperatura	Superficie m²		Valor-U W/(m²K)		Factor Siempre 1 (excepto "X")		Dif. de temperatura 1 K		Dif. de temperatura 2 K		P_T 1 W		P_T 2 W
Muro ext. - aire ext.	A	100,3	*	0,130	*	1,00	*	8,6	o bien	8,6	=	112	o bien	112
Muro ext. - terreno	B		*		*	1,00	*	-2,1	o bien	-2,1	=		o bien	
Techo / cubierta - Aire ext.	A	155,8	*	0,132	*	1,00	*	8,6	o bien	8,6	=	176	o bien	176
Solera / losa piso / forjado sanitario	B	139,4	*	0,116	*	1,00	*	-2,1	o bien	-2,1	=	-34	o bien	-34
	A		*		*	1,00	*	8,6	o bien	8,6	=		o bien	
	A		*		*	1,00	*	8,6	o bien	8,6	=		o bien	
	X		*		*	0,75	*	8,6	o bien	8,6	=		o bien	
Ventanas	A	18,6	*	0,715	*	1,00	*	8,6	o bien	8,6	=	114	o bien	114
Puerta exterior	A		*		*	1,00	*	8,6	o bien	8,6	=		o bien	
Puentes térmicos exteriores(longitud en m)	A		*		*	1,00	*	8,6	o bien	8,6	=		o bien	
Puentes térmicos perimetro (longitud en m)	P		*		*	1,00	*	-2,1	o bien	-2,1	=		o bien	
Puentes térmicos piso (longitud en m)	B		*		*	1,00	*	-2,1	o bien	-2,1	=		o bien	
Muro divisorio entre viviendas	I		*		*	1,00	*	3,0	o bien	3,0	=		o bien	
Corrección de radiación aire exterior				$A_{exterior}$ W/K		-4,2	*	8,6	o bien	8,6	=	-36	o bien	-36
Corrección de radiación cielo				$A_{irecielo}$ W/K		4,2	*	-4,8	o bien	-3,5	=	-20	o bien	-15
Carga de calor por transmisión P_T										Total	=	**311**	o bien	**316**

Carga de ventilación	V_V m³		$n_{V,equi,frac}$ 1/h		$n_{V,equi,frac}$ 1/h		c_{aire} Wh/(m³K)		Dif. de temperatura 1 K		Dif. de temperatura K		P_P 1 W		P_P 2 W
Exterior $P_{V,o}$	294	*	0,167	o bien	0,167	*	0,33	*	8,6	o bien	8,6	=	138	o bien	138
Terreno PL,e	294	*	0,000	o bien	0,000	*	0,33	*	-7,6	o bien	-7,6	=	0	o bien	0
Ventilación verano $P_{V,S}$	294	*	0,000	o bien	0,000	*	0,33	*	0,0	o bien	0,0	=	0	o bien	0
Carga de calor ventilación P_{Vent}												Total	**138**	o bien	**138**

Orientación de la superficie	Superficie m²		Valor g (Rad. perpendicular)		Factor de reducción (Compare hoja 'Ventanas')		Radiación 1 W/m²		Radiación 2 W/m²		P_T 1 W		P_T 2 W
Norte	5,1	*	0,1	*	0,06	*	90	o bien	90	=	2	o bien	2
Este	1,9	*	0,5	*	0,05	*	190	o bien	190	=	9	o bien	9
Sur	9,9	*	0,5	*	0,04	*	170	o bien	170	=	29	o bien	29
Oeste	1,9	*	0,5	*	0,06	*	180	o bien	180	=	10	o bien	10
Horizontal	0,0	*	0,0	*	0,40	*	350	o bien	350	=	0	o bien	0
Total superficies opacas											161	o bien	161
Carga solar P_S									Total	=	**212**	o bien	**212**

	Potencia específica W/m²		A_{SRE} m²		P_I 1 W		P_I 2 W
Carga interna de calor P_I	2,6	*	117	=	302	o bien	302

$P_T + P_{Vent} + P_{Acum} + P_I$	=	963	o bien	969	
Carga de refrigeración P_{ref}	=		969		W
Carga de refrigeración por área específica P_C / A_{SRE}	=		8,2		W/m²

Introduzca la temperatura mínima del aire de impulsión °C

			°C	°C
Temperatura aire de impulsión sin refrigeración	$\vartheta_{admis,min}$		27,3	27,3
			W	W
Para comparar: carga de refrigeración, transportable a través del aire de impulsión $P_{Impuls;Max}$		=	1190	1190
			W/m²	W/m²
		Específica:	10,1	10,1

(sí/no)

¿Aire acondicionado (refrigeración) posible a través del aire de impulsión?

Elevación diaria de temperatura interior

	Transmisión W		Ventilación W		Carga solar W		Tiempo h/d		Capacidad específica Wh/(m²K)		A_{SRE} m²			
(	316,3	+	138,3	+	211,8	) *	24	/ (	132	*	117	) =	1,0	K

Carga de humedad

De hoja 'Refrigeración'

Humedad abs. aire extracción	16,2	o bien	16,2	g/kg	Humedad abs. aire impulsió	13,7	o bien	13,7	g/kg
Flujo de aire exterior	16	o bien	16	kg/h	Flujo aire de impulsión	156	o bien	156	kg/h
Flujo aire ventilación verano	0	o bien	0	kg/h	**Carga de hum. aire impuls**	272	o bien	272	g/h
Carga de hum. aire admis.	66	o bien	66	g/h	**Carga interna humedad**	263	o bien	263	g/h

Entalpía de vaporización Wh/kg		g/kg		Carga de humedad g/h		Carga de humeda g/h		P_D 1 W		P_D 2 W
707,639	/	1000	*	601	o bien	601	=	425	o bien	425

Carga de humedad P_T	=	425	W
Carga de deshumidificación por área específica PT / A_{SRE}	=	3,6	W/m²

Valores promedio mensuales

	Enero	Febrerc	Marzo	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Octubre	Noviembre	Diciembre	
Demanda específica de refrigeración	0,0	0,0	0,0	0,0	0,0	2,5	4,0	4,0	0,0	0,0	0,0	0,0	kWh/m²
Demanda específica de deshumidificación	0,0	0,0	0,0	0,0	0,0	1,4	1,7	1,5	0,0	0,0	0,0	0,0	kWh/m²
Proporción sensible	100%	100%	100%	100%	100%	65%	70%	73%	100%	100%	100%	100%	

Cuota mínima de carga de refrigeración producida 65%

Sistema de distribución de calefacción y ACS

#

Temperatura interior:	20	°C	Temperatura interior verano:	25	°C
Tipo de edificio:	Vivienda unifamiliar aislada				
Superficie de referencia energética A_{SRE}:	117	m²			
Ocupación:	2,6	Personas			
Nr. de viviendas:	1				
Demanda anual de calefacción Q_{cal}	1356	kWh/a	Demanda anual de refrig. útil $q_{Refr.}$	1243	kWh/a
Duración de periodo de calefacción:	128	d	Duración de periodo de refrigeración:	122	d
Carga media de calefacción P_{Media}:	0,4	kW	Carga media de refrigeración P_{Media}:	0,4	kW
Aprovechamiento máx ganancias de calor adicionales	92%		Utilidad marginal de las pérdidas de calor adicionales:	99%	

Red de calefacción

			Dentro de la envolvente térmica					Fuera de la envolvente térmica					Valores totales	
			1	2	3	4	5	1	2	3	4	5	Absolutos	Específicos
Longitud de las tuberías de distribución	A_{Cal}	m												
Diámetro nominal de la tubería		mm												
Espesor del aislamiento		mm												
¿Reflectante?		-												
Conductividad térmica del aislamiento		W/(mK)	0,000											
Coeficiente de pérdidas de calor por m de tubería aislada		W/(mK)												
Calidad de aislamiento de los montajes, las suspensiones de tuberías, etc.		-	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna	1 - Ninguna		
Suplemento de puente térmico		W/K												
Coeficiente total de pérdidas de calor por m de tubería	Ψ	W/(mK)												
Temp. de la habitación por la que pasa la tubería	ϑ_X	°C	20	20	20	20	20	0,0	0,0	0,0	0,0	0,0		
Temperatura de ida de diseño	ϑ_V	°C	75,0	75,0	75,0	75,0	75,0	75,0	75,0	75,0	75,0	75,0		
Carga de calefacción de diseño	P_{cal}	kW	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7		
Control de temperatura de impulsión ('x' si corresponde)														
Temp. de retorno de diseño	ϑ_R	°C												
Emisión de calor anual por m de tubería	$q^*_{tub\ cal}$	kWh/(m·a)											kWh/a	kWh/(m²a)
Grado de aprovechamiento posible de emisión de calor	η_G	-												
Pérdidas anuales calor en la red de distribución de calef.	$Q_{tub\ Cal}$	kWh/a											0	0,0
Pérdidas de calor anuales por acumulador/tanque		kWh/a											5	0,0
Pérdidas anuales de calor en la red de calefacción		kWh/a											5	0,0
Rendimiento de la distribución de calor	$e_{a,HL}$	-											100%	

Distribución ACS

			Dentro de la envolvente térmica					Fuera de la envolvente térmica					Valores totales	
			1	2	3	4	5	1	2	3	4	5	Absolutos	Específicos
Temp. de la habitación por la que pasa la tubería	ϑ_X	°C	20,0	20,0	20,0	20,0	20,0							
Temperatura de ida de diseño	ϑ_{ida}	°C	**45,0**	45,0	45,0	45,0	45,0	45,0	45,0	45,0	45,0	45,0		
Tuberías circulación ACS														
Longitud de las tuberías de circulación (ida + retorno)	L_{Circ}	m	**32,0**											
Diámetro nominal de la tubería		mm	**20**											
Espesor del aislamiento		mm	**40**											
¿Reflectante?		-												
Conductividad térmica del aislamiento		W/(mK)	**0,036**											
Coeficiente de pérdidas de calor por m de tubería aislada		W/(mK)	0,138											
Calidad de aislamiento de los montajes, las suspensiones de tuberías, etc.		-	**2 - Moderado**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**	**1 - Ninguna**		
Suplemento de puente térmico		W/K	1,720											
Coeficiente total de pérdidas de calor por m de tubería	Ψ	W/(mK)	**0,192**											
Tiempo de funcionamiento de la circulación al día	td_{circ}	h/d	**0,2**											
Temp. de retorno de diseño	ϑ_R	°C	42											
Tiempo de funcionamiento de la circulación al año	t_{dcirc}	h/a	73											
Calor anual emitido por m de tubería	q^*_{circ}	kWh/m/a	0										kWh/a	kWh/(m²a)
Pérdida de calor anual de las tuberías de circulación	Q_{circ}	kWh/a	**10**										**10**	**0,1**
Tuberías individuales ACS														
Diámetro exterior del tubo	d_{Red}	m	**0,020**											
Longitud total de las tuberías individuales	L_{red}	m	**12,00**											
Cantidad de aperturas de grifo en el edificio	$n_{puntos\ apertura}$	-	**7,00**											
Longitud media de tubería por punto de apertura	$L_{U,\ promedio}$	m	1,7											
Aperturas de grifo al día		-	**6**											
Días de uso anuales (d/a)		d	**365**											
Emisión de calor por cada apertura de grifo	$q_{Individual}$	kWh/apertura por grifo	0,0124											
Cantidad de aperturas de grifo por persona y año	n_{toma}	Aperturas de grifo por año	2190										kWh/a	kWh/(m²a)
Pérdida de calor anual de las tuberías individuales	Q_{Red}	kWh/a	**71**										**71**	**0,6**
													kWh/a	kWh/(m²a)
Pérdidas de calor totales de la distribución de ACS	Q_{PC}												**82**	**0,7**
Rendimiento de las tuberías de distribución de ACS	$e_{a,HL}$	-											**107%**	

Pérdidas de calor en el almacenamiento

		Almacenamiento 1	Almacenamiento 2	Tanque de almacenamiento de inercia (sól	Unidad compacta		
Selección del tanque/acumulador de almacenamiento		2-Sólo ACS	0-Sin tanque/acumulador de	1-Tanque/acumulador de alm	0-No		
Almacenamiento necesario para BC		x		(x)			
Conexión ACS Solar							
Ratio de pérdida de calor	W/K	0,6		0,4			
Volumen de almacenamiento	Litros	150		30	---		
Fracción 'en espera'	-						
Ubicación del tanque/acumulador de almacenamiento, en el interior o exterior de la envolvente térmica		1-Interior	1-Interior	1-Interior			
Temperatura del cuarto de instalaciones	°C	20,0		20,0			
Temperatura característica del tanque/acumulador de almacenamiento	°C	45,0		75,0			
Introducción de la temperatura de almacenamiento	°C	45,0					
Pérdidas medias de calor del tanque /acumulador en modo "espera"	W	15		22			
Pérdidas de calor adicionales acumulador/tanque solar, operación solar	W			---	---		
Posible factor de utilización de las pérdidas de calor		---	---	92%	---	kWh/a	kWh/(m²a)
Pérdidas de calor anuales por acumulador/tanque ACS	kWh/a	131		---		131	1,1
Pérdidas de calor anuales acumulador de inercia		---	---	5	---		

Cálculo auxiliar - pérdidas de calor a través de tanque/acumulador de almacenamiento según las clases de eficiencia de la U

Volumen del tanque de almacenamiento	Litros	150,0		30,0
Clase ErP	-	A+	C	A+
Máximas pérdidas de calor admisibles en espera	W	29		18
Factor de pérdida de calor para el cálculo en PHPP	W/K	0,6		0,4

Demanda energética total de ACS

		kWh/a	kWh/(m²a)
Pérdidas calor de ACS en distribución y almacenamiento	Q_{PC}	213	1,8
Rendimiento distribución de ACS y almacenamiento	$e_{a,WL}$	118%	
Demanda total de calor del sistema de ACS		kWh/a	kWh/(m²a)
Incluyendo tanque/acumulador de almacenamiento	Q_{totAC}	1399	11,9

Distribución red de refrigeración

			Dentro de la envolvente térmica					Fuera de la envolvente térmica					Valores totales	
			1	2	3	4	5	1	2	3	4	5	Absolutos	Introducción
Longitud de las tuberías de distribución	A_{Cal}	m												
Diámetro nominal de la tubería		mm												
Espesor del aislamiento		mm												
¿Reflectante?		-												
Conductividad térmica del aislamiento		W/(mK)												
Coeficiente de pérdida de calor por m de tubería	Ψ	W/(mK)												
Temp. de la habitación por la que pasa la tubería	ϑ_X	°C	25,0	25,0	25,0	25,0	25,0	**25,0**	25,0	25,0	25,0	25,0		
Temperatura de ida de diseño	ϑ_V	°C	**6,0**	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0		
Dimensionado de la carga de refrigeración del sistema	$P_{refrigeración}$	kW												
Control de temperatura de impulsión ('x' si corresponde)														
Temp. de retorno de diseño	ϑ_R	°C												
Absorción de calor anual por m de tubería	$q^*_{tub\ cal}$	kWh/(m·a)												
Posible factor de utilización de esta absorción de calor	η_G	-											kWh/a	kWh/(m²a)
Pérdidas anuales de calor en red de distribución de refrig.	$Q_{tub\ Cal}$	kWh/a											**0**	**0,0**
Rendimiento de las tuberías de distribución de agua fría	$e_{a,HL}$	-											**100%**	

Demanda de electricidad para edificios residenciales

Nr. de viviendas		1
Personas	1	2,6
Superficie habitable (m²)	2	117
Demanda calefacción [kWh/(m²a)]	3	11,5

Factores PER and EP (KWh/kWh)		
Electricidad:	1,20	2,6
Fuente de energía no eléctrica para cocinar, secar:	1,20	2,6
Fuente de energía para calefacción:	1,10	2,6
Fuente de energía para ACS:	1,14	2,6

Contribución solar de ACS para lavar ropa y platos	
Índice de rendimiento mínimo ACS	16%
Índice de rendimiento mínimo calefacción	42%

Columna Nr.	1	2	3			4	5		6		7	8	8a	9	10	11	12	13
Uso	¿Existente? (1/0)	¿Dentro de la envolvente térmica? (1/0)	Demanda estándar			Grado de aprovechamiento	Frecuencia de uso anual		Valor de referencia		Energía útil (kWh/a)	Cuota eléctrica	Cuota no eléctrica	**Demanda de electricidad (kWh/a)**	Demanda aumentada/reducida	Índice de rendimiento mínimo	Cuota de aportación solar	Demanda no eléctrica (kWh/a)
Lavavajillas	1	1	1,10	kWh/uso		* 1,00	* 65	/(P*a)	* 2,6	p	= 188	* 100%		= 188				
2-Conexión agua fría												*	0%		* (1+ 0,30)	* 0,16	*(1-) =	
Lavar ropa	1	1	1,10	kWh/uso		* 1,00	* 57	/(P*a)	* 2,6	p	= 165	* 100%		= 165				
2-Conexión agua fría												*	0%		* (1+ 0,05)	* 0,16	*(1-) =	
Secado de ropa:	1	1	3,50	kWh/uso	Humedad residual 0,60	0,88	* 57	/(P*a)	* 2,6	p	= 459	100%		= 459				
4-Secadora de condensación											= 0		0%			1,00 *		0
Consumo energético por evaporación	0	1	3,13	kWh/uso		* 0,60	* 57	/(P*a)	* 2,6	p	= 0	*	100%		* (1+ 0,00)	* 0,42	*(1- 0,79) =	0
Refrigerar	1	1	0,78	kWh/d		* 1,00	* 365	d/a	* 1	Vivier	= 285	* 100%		= 285				
Congelador	1	1	0,88	kWh/d		* 1,00	* 365	d/a	* 1	Vivier	= 321	* 100%		= 321				
o combinaciones	0	1	1,00	kWh/d		* 1,00	* 365	d/a	* 1	Vivier	= 0	* 100%		= 0				
Cocinar con	1	1	0,25	kWh/uso		* 1,00	* 500	/(P*a)	* 2,6	p	= 329	* 100%		= 329				
1-Electricidad					Eficiencia media de iluminación [lm/W]							*	0%					0
Iluminación	1	1	14	W	50	* 1,00	* 2,90	kh/(P*a)	* 2,6	p	= 110	* 100%		= 110				
Electrónica	1	1	80	W		* 1,00	* 0,55	kh/(P*a)	* 2,6	p	= 116	* 100%		= 116				
Aparatos pequeños, etc.	1	1	50	kWh		* 1,00	* 1,00	/(P*a)	* 2,6	p	= 131	* 100%		= 131				
Total elect. aux.											563			563				
Otros:																		
				kWh/a							0			0				
				kWh/a							0			0				
				kWh/a							0			0				
Total											2666 kWh			2666 kWh	ACS no eléctrica lavar ropa y platos	0	kWh	0
Valor caract.														22,7 kWh/(m²a)	No renovable y no eléctrico ACS lavar ropa y platos	0,0	kWh/(m²a)	0,0
Valor máx. recomendado														18				

Electricidad-Aux

##

SRE (sup. ref. energética)	117	m²
Periodo de calefacción	128	d
Caudal de aire	294	m³
Viviendas	1	viviendas

Eficiencia de recuperación de calor del ap	0,83	
Tiempo uso sistema ventilación invierno	3,07	kh/a
Tiempo uso sistema ventilación verano	5,69	kh/a
Tasa de renovación de aire	0,31	h^{-1}

Demanda de calefacción	12	kWh/(m²a)
Potencia nominal de calor de la caldera	15	kW
Demanda de calor de la instalación de ACS	1399	kWh/a
Temperatura de ida de diseño	75	°C

Columna Nr.	1	2	3		4		5		6		7	8	9	10	11
Uso	¿Existente?[1/0]	Dentro de la envolvente térmica [1/0]	Demanda estándar		Grado de aprovechamiento		Tiempo de uso		Valor de referencia		**Demanda de electricidad [kWh/a]**	Disponibilidad como GIC	Usado en el periodo de tiempo [kh/a]	**Cargas internas de calor invierno [W]**	**Cargas internas de calor verano [W]**
Sistema de ventilación															
Ventilación en invierno	1		0,40	Wh/m³	0,31	h^{-1}	3,1	kh/a	294	m³	113	Incluído en la eficiencia de la recuperación de calor			
Descongelación RC	1	1	Datos introducidos de la hoja de cálculo 'Ventilación' o 'Ventilación-Ad'								20	0,2	3,07	1	
Ventilación en verano	1	0,90	0,40	Wh/m³	0,45	h^{-1}	5,7	kh/a	294	m³	301	1,0	5,69		48
												Fuentes internas de calor 'Ventilación adicional en verano':			0,0
Ventilación ad. verano	0		0,00	Wh/m³	0,00	h^{-1}	5,7	kh/a	294	m³	0	1,0	5,69		
Instalación de calefacción					Con control / Sin control [1/0]										
Introducción de datos de la potencia nominal de la bomba				W											
Bomba de circulación calef.			58	W	1,0		3,1	kh/a	1		0	1,0	3,07	0	
Potencia eléctrica de la calentador en caso de 30% de carga				W											
Energía auxiliar calentador calefacción	0	0	55	W	1,00		0,00	kh/a	1		0	1,0	3,07	0	
Energía aux. - calentador de leña o pellets	0	0	Introducción de datos en la hoja de cálculo 'Caldera'. Demanda de energía auxiliar incluyendo la posib								0	1,0	3,07	0	
Instalación de ACS															
Introducción de datos de la potencia media de la bomba				W											
Bomba de circulación ACS	1	1	28	W	1,00		4,6	kh/a	1		129	1,0	8,76	15	15
Introducción de datos de la potencia nominal de la bomba				W											
Bomba de carga de acumulador/tanque de ACS			53	W	1,00		0,1	kh/a	1		0	1,0	8,76	0	0
potencia eléctrica de la calentador con 100% de carga				W											
Energía auxiliar calentador ACS	0	0	165	W	1,00		0,0	kh/a	1		0	1,0	8,76	0	0
Introducción potencia nominal de bomba del sistema de energía solar				W											
Electricidad auxiliar solar	0		38	W	1,00		1,8	kh/a	1		0	1,0	8,76	0	0
Electricidad auxiliar refrigeración y deshumidificación															
Elect. aux. refrigeración				kWh/a	1,00		1,0		1		0	1,0	5,69		0
Elect. aux. deshumidificación				kWh/a	1,00		1,0		1		0	1,0	5,69		0
Electricidad auxiliar otros															
Electricidad auxiliar otros				kWh/a	1,00		1,0		1		0	1,0	8,76	0	0
Total											563			16	62
Demanda específica	kWh/(m²a) (sup. referen. energét.)										**4,8**				

Energía Primaria Renovable PER

#¡VALOR!

Tipo de edificio: **Vivienda unifamiliar aislada**

Superficie de referencia energética A_{SRE}:	117	m²
Huella proyectada del edificio $A_{Proyectada}$:	0	m²
Demanda calef. incl. distribución y prot. hidr. contra congelación:	12	kWh/(m²a)
Demanda energé. refrige. incl. deshumidifi.:	19	kWh/(m²a)
Demanda ACS incluye. distribución:	12	kWh/(m²a)

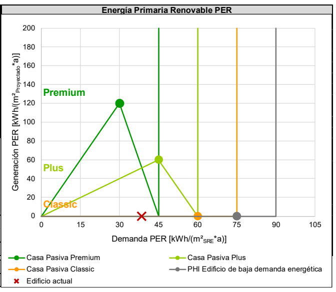
Selección del sistema(s) de generación de calor	Margen de contribución (energía útil)		
Tipo generador de calor primario	**Calefacción**	**ACS**	**Datos adicionales en las hojas:**
2-Bomba(s) de calor	100%	100%	BC, posiblemente BC-Terreno
Generación de calor secundario (opcional y diferente)			
-	0%	0%	-

Demanda de energía **Referencia: Superficie de referencia energética**	**Eficiencia**		**Energía final**		**PER**			**EP**		**CO_2**	
	Cálculo -	Valor definido por el usuario -	Contribución (energía final)	**Demanda de energía final** kWh/(m²a)	Factor PER kWh/kWh	Factor PER efectivo (incly. contingente biomasa) kWh/kWh	**Valor específico PER** kWh/(m²a)	Factor EP kWh/kWh	Valor EP kWh/(m²a)	Factor emisiones CO_2 (CO_2-eq) kg/kWh	Emisiones CO_2eq kg/(m²a)
								1-Factores EP (no-renovable) Certificación PHI		1-Factores CO2 GEMIS (Alemania)	
							38,5		82,5		16,9
Datos para calefacción			100%			1,10	**6,5**	2,60	**15,3**		**3,1**
Electricidad (Unidad compacta BC)					1,90			2,60		0,532	
Electricidad (bomba de calor)	2,44		100%	4,7	1,90	1,10	5,2	2,60	12,3	0,532	2,5
Calefacción urbana: 1-Ninguna					2,8|4,5|3,3					0,000	
Madera y otra biomasa					1,10			-		-	
Gas natural / gas RE					1,75			1,10		0,250	
Gasóleo / RE metanol					2,30			1,10		0,320	
Sistema solar térmico											
Electricidad (directa)					1,90			2,60		0,532	
Electricidad aux. (calefacción, ventilación durante el invierno)				1,1	1,90	1,10	1,3	2,60	3,0	0,532	0,6
Refrigeración y deshumidificación					1,45		**7,2**		**12,9**		**2,6**
Electricidad para refrigeración (bomba de calor)	8,00			2,4	1,45		3,5	2,60	6,2	0,532	1,3
Electricidad auxiliar refrigeración y ventilación en verano				2,6	1,45		3,7	2,60	6,7	0,532	1,4
Electricidad para deshumidificación (bomba de calor)					1,65			2,60		0,532	
Electricidad auxiliar (deshumidificación)					1,65			2,60		0,532	
Generación ACS			100%			1,14	**3,4**	2,60	**7,8**		**1,6**
Electricidad (Unidad compacta BC)					1,15			2,60		0,532	
Electricidad (bomba de calor)	6,30		100%	1,9	1,15	1,14	2,2	2,60	4,9	0,532	1,0
Calefacción urbana: 1-Ninguna					2,8|4,5|3,3					0,000	
Madera y otra biomasa					1,10			-		-	
Gas natural / gas RE					1,75			1,10		0,250	
Gasóleo / Metanol					2,30			1,10		0,320	
Sistema solar térmico											
Electricidad (directa)					1,15			2,60		0,532	
Electricidad aux. (ACS + ACS-Solar)				1,1	1,15	1,14	1,3	2,60	2,9	0,532	0,6
Electricidad doméstica				**17,9**		1,19	**21,4**		**46,6**		**9,5**
Electricidad (doméstica o iluminación no residencial, etc.)				17,9	1,20	1,19	21,4	2,60	46,6	0,532	9,5
Electricidad auxiliar (otros)					1,20			2,60		0,532	
Gas / Gas RE secar / cocinar				**0,0**	1,75		**0,0**	2,60	**0,0**	0,270	**0,0**

Generación de Energía **Referencia: Superficie de la huella proyectada del edificio**	**Energía final**		**PER**		**EP**		**CO_2**	
	Generación energía final kWh/a	**Generación energía final** **kWh/(m²$A_{Proyectada}$*a)**	Factor PER kWh/kWh	**Valor específico PER** kWh/(m²$A_{Proyectada}$a)	Factor Energía Primaria kWh/kWh	Valor EP kWh/(m²a)	Factor emisión (CO_2-eq) kg/kWh	Emisiones CO_2eq kg/a
				0,0		**0,0**		**0,0**
Electricidad IFV	0	0,0	1,00	0,0	-		-	
Sistema solar térmico	0	0,0	-	0,0	1,22	0,0		
		0,0						

Requisito para la demanda de EP en el caso de la comprobación según EP (no renovable) [kWh/(m²a)]	-	**El edificio actual alcanza la siguiente clase**	**83**	**¿Requerimiento alcanzado?**	-

Estándar energético alcanzable a través de la comprobación de energía primaria renovable (evaluación de los aspectos individuales)	**Energía útil, cumplimiento**				**Hermeticidad**
	Dem. Cal. Anual SRE kWh/(m²a)	**Carga calefacción** SRE W/m²	**Energía útil refrig.** SRE kWh/(m²a)	**Carga refrigerac.** SRE W/m²	**n_{50}** 1/h
Requerimiento Casa Pasiva Premium Requerimiento Casa Pasiva Plus Requerimiento Casa Pasiva Classic	15	10	20	10	0,60
Requerimiento PHI Edificio de baja demanda energética	30		35		1,00
El edificio actual alcanza la siguiente clase	12	14	15	8	0,6
	Premium		Premium		Premium



Cuadro resumen Aunque, desde el punto de vista científico no es del todo correcto, se sumarán aquí diferentes portadores energéticos. Esto se hace para cumplir con los criterios de otros estándares energéticos.	**Energía final** MWh/a	**Valor específico PER** MWh/a	**Valor EP** 1-Factores EP (no-renovable) Certificación PHI MWh/a	**Emisiones CO2eq** 1-Factores CO2 GEMIS (Alemania) kg/a	**Equilibrio sustitución CO_{2eq}** 1-Factores CO2 GEMIS (Alemania) kg/a
Demanda	**3,7**	**4,5**	9,69	1983	1983
Generación	**0,0**	**0,0**	0,00	0	0
Demanda, generación acumulada (balance anual)	3,73	4,52	9,69	1983	1983
Demanda sin electricidad doméstica	**1,6**	**2,0**	4,22	864	864
Demanda sin electricidad doméstica, cum. generación	1,62	2,01	4,22	864	864

-

Bomba de calor (BC)

#¡VALOR!

		Tipo de edificio:	Vivienda unifamiliar aislada	
		SRE A_{SRE}:	117	m²
Proporción de cobertura de la demanda de calefacción		*(Hoja de cálculo 'PER')*	100%	
Demanda de calefacción + pérdidas por distribución	$Q_{Cal}+Q_{tub\ Cal}$:	*('Distribución+ACS')*	1361	kWh/a
Proporción solar calefacción	$\eta_{Solar,\ Cal}$	*(Hoja de cálculo 'ACS-Solar')*	0%	
Demanda efectiva de calefacción	$Q_{Cal,ef}=QCal*(1-\eta_{Solar,\ Cal})$		**1361**	kWh/a
Proporción de cobertura de demanda de ACS		*(Hoja de cálculo 'PER')*	100%	
Demanda total de calor del sistema de ACS	Q_{totACS}	*('Distribución+ACS')*	1399	kWh/a
Proporción solar ACS	$\eta_{Solar,\ ACS}$	*(Hoja de cálculo 'ACS-Solar')*	0%	
Demanda de ACS efectiva	$Q_{ACS,ef}=Q_{ACS}*(1-\eta_{Solar,\ ACS})$		**1399**	kWh/a
Número de bombas de calor en el sistema			2	
Función			Calefacción y ACS	
Datos para calefacción				
Selección de BC: 4-LG MU4R25		Fuente de calor:	1-Aire exterior	
Selección de sistema de distribución			2-Radiadores	
Temperatura de cálculo sistema de calefacción	$\theta_{diseño}$	*('Distribución+ACS')*	75,00	°C
Potencia nominal del sistema de distribución	P_{nom}		1,66	kW
Sistema de distribución (a ser completado sólo por usuarios experimentados)				
Potencia nominal del sistema de distribución	P_{nom}			kW
Exponente de radiador	n			
Tanque/acumulador para calefacción (acumulador de inercia hoja 'Distribución+ACS')			1-Sí	
Pérdidas de calor específicas por almacenamiento	$U * A_{Acum}$		0,4	W/K
Ubicación acumulador/tanque			1-Interior	
Temperatura interior (ubicación del almacenamiento: fuera de la envolvente térmica)		*('Distribución+ACS')*	20,00	°C
Temperatura de disipador de bomba de calor para calefacción	$\theta_{disminución}$		76,50	°C
Datos para ACS				
Selección de BC: 5-NUOS 150		Fuente de calor:	1-Aire exterior	
Temperatura ACS		*('Distribución+ACS')*	45,00	°C
Posición tanque de ACS ('tanque/acumulador 1' en hoja 'Distribución+ACS')			1-Interior	
Pérdidas de calor específicas por almacenamiento	$U * A_{Acum}$		0,6	W/K
Temperatura interior (ubicación del almacenamiento: fuera de la envolvente térmica)		*('Distribución+ACS')*	20,00	°C
Tipo de calefacción de respaldo			1-Calendador de inmersión eléctrico	
Δθ Calentador de paso eléctrico				K
Opciones adicionales en el caso de <u>una</u> bomba de calor para dos funciones: Calefacción & ACS				
Misma temperatura de disipador de bomba de calor para calefacción y ACS			0-No	
Prioridad bomba de calor		*(Fabricante, datos técnicos)*	1-Prioridad-ACS	
Estrategia de control				
Estrategia de control de la bomba de calor			1-Encendido / Apagado	
Terreno y agua subterránea como fuente para la bomba de calor				
Profundidad (horizontal / vertical) intercambiador de calor en subsue	z			m
Potencia de la bomba del intercambiador de calor subterráneo	P_{pump}			kW

-

Calefacción

Bomba de calor: LG MU4R25

Fuente: 1-Aire exterior

	θ_fuente °C	θ_disipador °C	Capacidad de calefacción kW	COP
Punto de prueba 1	3,5	38,4	10,3	5,3
Punto de prueba 2	-0,9	36,4	9,1	4,9
Punto de prueba 3	-5,2	34,4	7,9	4,2
Punto de prueba 4	-9,6	32,4	6,7	3,3
Punto de prueba 5	-11,8	31,4	6,1	3,1
Punto de prueba 6	-16,1	29,5	5,0	2,6
Punto de prueba 7	8,7	34,1	5,1	6,4
Punto de prueba 8	3,7	32,6	4,6	5,5
Punto de prueba 9	-1,2	31,1	4,0	4,8
Punto de prueba 10	-6,2	29,6	3,4	4,1
Punto de prueba 11	-8,7	28,9	3,1	3,8
Punto de prueba 12	-13,6	27,4	2,5	3,0
Punto de prueba 13				
Punto de prueba 14				
Punto de prueba 15				

Diferencia de temperatura en disipador $\Delta\theta_{Disipador}$ K

ACS

Bomba de calor: NUOS 150

Fuente: 1-Aire exterior

	θ_fuente °C	θ_disipador °C	Capacidad de calefacción kW	COP
Punto de prueba 1	2,0	62,0	1,8	2,6
Punto de prueba 2	7,0	62,0	2,5	3,5
Punto de prueba 3	14,0	62,0	2,7	3,8
Punto de prueba 4	20,0	62,0	3,7	5,3
Punto de prueba 5				
Punto de prueba 6				
Punto de prueba 7				
Punto de prueba 8				
Punto de prueba 9				
Punto de prueba 10				
Punto de prueba 11				
Punto de prueba 12				
Punto de prueba 13				
Punto de prueba 14				
Punto de prueba 15				

Diferencia de temperatura en disipador $\Delta\theta_{Disipador}$ K

Consumo eléctrico de bomba (agua subterránea)	$Q_{El,Bomba}$	0	kWh/a
Energía por electricidad directa	$Q_{El,dir}$	0	kWh/a
Aportación de calor la BC al espacio calefactado	$Q_{BC,Calef}$	1337	kWh/a
Aportación de ACS de la BC en invierno	$Q_{BC,ACS,Invierno}$	262	kWh/a
Aportación de ACS de la BC en verano	$Q_{BC,ACS,Verano}$	1137	kWh/a
Calefacción generada por BC sin pérdidas de calor por acumula	$Q_{BC,Calef}$	1337	kWh/a
Aportación de ACS de la BC en invierno sin pérdidas por almac	$Q_{BC,ACS,Invierno}$	237	kWh/a
Aportación de ACS de la BC en verano sin pérdidas por almace	$Q_{BC,ACS,Verano}$	1030	kWh/a
Consumo eléctrico de la BC	Qel_{HP}	779	kWh/a

		1. HP: Calefacción o calefacción y ACS	**2. BC: Agua calie**
Factor de rendimiento estacional de la bomba de calor	SPF_{H-1}	**2,40**	**6,30**
		kWh/a	kWh/(m²a)
Demanda de energía final del generador de calor	Q_{final}	**779**	**6,6**
Demanda anual de energía primaria (EP)		**2026**	**17,3**
		kg/a	kg/(m²a)
Emisión anual de CO_2 equivalente		**415**	**3,5**

Tabla de factores PER y EP, así como los factores de emisión de CO_2 equivalente de diferentes portadores de energía y usos de diferentes fuentes

			Transferido a la hoja de cálc	
Tipo de energía	Número	Fuentes de energía	Factor PER	**1-Factores EP (no-renovable) Certificación PHI**
			$kWh_{prim-el}$/ kWh_{Final}	kWh_{prim}/ kWh_{Final}
	10	Ninguno		
Combustible	20	Gasóleo	*2,30*	**1,10**
	30	Gas natural	*1,75*	**1,10**
	31	Gases Licuados del Petróleo GLP	*1,75*	**1,10**
	41	Hulla	*2,30*	**1,10**
	42	Lignito	*2,30*	**1,20**
	32	Biogás	*1,10*	**1,10**
	21	Aceite de pirolisis o aceite bio	*1,10*	**1,10**
	43	Madera (Biomasa)	*1,10*	**0,20**
	44	Troncos de madera	*1,10*	**0,20**
	50	Pellets	*1,10*	**0,20**
	46	Astillas de bosque	*1,10*	**0,20**
	47	Astillas de madera de álamo/chopo	*1,10*	**0,20**
	33	RE-Gas	1,75	
	22	RE-Metanol	2,30	
	48	Biomasa	1,10	
Electricidad	60	Electricidad de la red (mezcla renovable/no renovable)		**2,60**
	61	Mezcla Energía de CHC		**2,40**
	00	Electricidad primaria	1,00	
	01	Electricidad doméstica	**1,20**	**2,60**
	02	Electricidad para ACS	**1,15**	**2,60**
	03	Electricidad para calefacción	**1,90**	**2,60**
	04	Electricidad para refrigeración	**1,45**	**2,60**
	05	Electricidad para deshumidificación	**1,65**	**2,60**
	06	Platzhalter_EE-Stromanwendung	**-**	**2,60**
	62	Electricidad procedente de energía fot	*1,00*	**0,00**
	63	Paneles de energía fotovoltaicos mon	*1,00*	**0,00**
	64	Paneles de energía fotovoltaicos policr	*1,00*	**0,00**
	65	Energía eólica costera	*1,00*	**0,00**
	66	Energía eólica no costera	*1,00*	**0,00**
	67	Central hidroeléctrica > 10MW	*1,00*	**0,00**
Energía del medio ambiente, energía solar térmica	71	Calor del terreno, energía geotérmica	0,00	**0,00**
	72	Alta temperatura ambiente	0,00	**0,00**
	73	Baja temperatura ambiente	0,00	**0,00**
	80	Energía solar térmica colector plano (g	*1,00*	**0,00**
	81	Energía solar térmica colector tubos e	*1,00*	**0,00**
	74	Calor perdido	0,00	**0,00**
El portador de energía definido por el usuario (para la ge	98	**Eigener Energieträger**		
factores definidos por el usuario para la demanda en las	99			
	1	1-Ninguna		**0,00**
Calefacción de distrito	10	10-Cogeneración hulla, hasta 70% aprovechamiento prod		**0,80**
	11	11-Cogeneración hulla, hasta 35% aprovechamiento prod		**1,10**
	12	12-Caldera hulla, 0% aprovechamiento producción electri		**1,50**
Gas CHP (pequeña)	20	20-Cogeneración gas (pequeña), 70%	Cálculo en 'Distrito calefacción' hoja de cálculo	**0,70**
	21	21-Cogeneración gas (pequeña), 35%		**1,10**
	22	22-Caldera Gas, 0% aprovechamiento		**1,50**
Gasóleo CHP (pequeña)	30	30-Cogeneración gasoil (pequeña), 70		**0,80**
	31	31-Cogeneración gasoil (pequeña), 35		**1,10**
	32	32-Caldera gasoil, 0% aprovechamiento producción elect		**1,50**
Calefacción urbana: determinada por el usuario	40	**40-Eigene Eingabe: 90% KWK**		**0,80**
Calefacción urbana planta de cogeneración	13	Combustible fósil		**0,70**
	14	Combustible renovable		**0,00**
Calefacción urbana planta de calefacción	15	Combustible fósil		**1,30**
	16	Combustible renovable		**0,10**

Generador de calor			x) Será usado gas
Nr.	Tipo	Combustible (Hoja de cálculo 'Comparación')	
1	1-Ninguna		
10	10-Caldera de condensación de gas mejorada	1	x
11	11-Caldera de condensación de gasoil mejorada	2	
12	12-Caldera de condensación de gas	1	x
13	13-Caldera gasoil	2	
20	20-Caldera de baja temperatura de gas	1	x
21	21-Caldera de baja temperatura de gasoil	2	
30	30-Combustión de leña (aporte de calor directo e indirecto)	3	
31	31-Combustión de pellets (aporte de calor directo e indirecto)	4	
32	32-Combustión de pellets (sólo aporte de calor indirecto)	4	
40	40-Reserva		

Lavavajillas y lavadoras
1-Conexión ACS
2-Conexión agua fría

Secado de ropa	Disponibilidad electricidad	Disponibilidad evaporación
1-Tendedero	1	1
2-Armario de secado (frío)	1	1
3-Armario secado (frío) aire extracción	0,9	0,9
4-Secadora de condensación	0,7	0
5-Secadora ropa aire extracción (elect.)	1	1
6-Secadora ropa aire extracción (gas)	1	1

Cocinar	Cuota eléctrica	Factor Energía Primaria	Factor de CO_2	Factor-PER
1-Electricidad	100%	**2,60**	**0,53**	**1,20**
2-Natural gas	0%	**1,10**	**0,25**	**1,75**
3-GLP	0%	**1,10**	**0,27**	**1,75**