buildings

Article

Comparative Analysis of the Effect of the Evolution of Energy Saving Regulations on the Indoor Summer Comfort of Five Homes on the Coast of the Basque Country

Jorge Otaegi *, Rufino J. Hernández, Xabat Oregi, Alexander Martín-Garín and Iñigo Rodríguez-Vidal

CAVIAR Research Group, Department of Architecture, University of the Basque Country UPV/EHU, Plaza Oñati, 2, 20018 Donostia-San Sebastián, Spain; rufinojavier.hernandez@ehu.eus (R.J.H.); xabat.oregi@ehu.eus (X.O.); alexander.martin@ehu.eus (A.M.-G.); inigo.rodriguez@ehu.eus (I.R.-V.)

* Correspondence: jorge.otaegui@ehu.eus

Abstract: In the last decade, several European directives have been established to contribute to the 2020, 2030 and 2050 energy saving targets and impose energy efficiency requirements for new construction, existing buildings and building renovation operations. One of the ways to achieve said objectives is to rely on the most demanding energy efficiency labels existing in Europe, such as Passivhaus, and to implement similar concepts into the national energy regulations of European countries based on a high-performance thermal envelope (high insulation and high-performance windows), high airtightness and high-performance heat-recovery ventilation systems, and solar heat harvesting. This energy conservation concept has shown to be effective for houses with low-density occupation in cold climates, but may cause severe overheating problems in denser collective housing in temperate and hot climates with higher solar radiation. To assess this impact, five flats in three developments from different periods that range from no insulation at all to a nZEB, Passivhaus-certified high-rise are compared in this paper, using data from a monitoring campaign during the summer of 2020. The results show and quantify the strong impact the evolution of the energy saving regulatory trend has had on summer indoor comfort, which may in some cases lead to previously unnecessary air conditioning for cooling and, ultimately, be counterproductive towards the end goals of reducing energy consumption and greenhouse-effect gas emissions and mitigating climate change.

Keywords: thermal comfort; overheating; nZEB; Passivhaus; collective housing; monitoring campaign; post-occupancy evaluation

check for updates

Citation: Otaegi, J.; Hernández, R.J.; Oregi, X.; Martín-Garín, A.; Rodríguez-Vidal, I. Comparative Analysis of the Effect of the Evolution of Energy Saving Regulations on the Indoor Summer Comfort of Five Homes on the Coast of the Basque Country. *Buildings* **2022**, *12*, 1047. https://doi.org/10.3390/buildings12071047

Academic Editors: Wei Liu, Manuel Carlos Gameiro da Silva and Dayi Lai

Received: 1 July 2022
Accepted: 14 July 2022
Published: 19 July 2022

1. Introduction

1.1. Background and Aims

The economic, social and sustainability risks posed by climate change, evidenced first with the consequences of the energy crisis of the 1970s that put energy dependence in the spotlight [1], have led to the development of international agreements that seek to limit the use of fossil fuels and reduce the environmental impact of all human activities, including the construction and operation of buildings.

The long-term strategy for 2050 of the European Union establishes a roadmap towards a low-carbon economy by reducing greenhouse gases (GHG), setting an emission reduction target of 90% for the building sector for the year 2050 with respect to the emissions of 1990 [2]. Led by the Council of Europe and the European Parliament's regulatory [3,4] and strategic [5,6] work, the objective of reducing CO^2 emissions and promoting the use of renewable energies has driven a rapid evolution of national energy saving regulations, focusing on the improvement of the thermal envelope of buildings and the reduction of both total primary and non-renewable energy consumption [7].

In parallel, the social interest in green buildings has led to the implementation of different voluntary green certification seals and schemes that oblige the buildings to be endowed with different design methodologies and energy and ecological efficiency analyses such as BREEAM [8], LEED [9], Passivhaus [10], Minergie [11], CASBEE [12] and others.

Numerous studies warn of the problems arising from the increase in the performance of the envelope without taking into account the climatic and social conditions of each location, or expose the problems of a poor implementation of said standards [13–21].

However, the body of research based on the monitoring of real homes is still insufficient and mainly focused on single-family or semi-detached houses [13,16,20–22]. Following on from two previous studies [23,24] resulting from a monitoring campaign in the world's tallest Passivhaus building [25], this article analyzes the impact of the above-mentioned regulatory trend on the comfort of occupants of collective housing in the temperate climate of the Basque Country, Spain, and performs a comparative analysis with two older non-nZEB dwellings.

To this end, this article first presents the evolution of the national energy efficiency regulations in Spain, as well as the implementation of private green building certification schemes in this region. Then, this paper briefly analyzes the relevant literature and the most important challenges that have arose (namely, the winter-centered design mindset and an unexpected increase in summer overheating) and the cultural and social differences between the birthplace of the passive design concept and southern Europe. In Section 2, the case studies are introduced comprehensively, including their construction, occupants, surroundings and micro-climate analysis, and the methodology and data collection are explained. In the following sections, the comparative analysis is performed and results are discussed in Section 4 before drawing the conclusions.

1.2. Evolution of the National Energy Efficiency Regulations for Buildings in Spain

National energy efficiency regulations have been converging in recent years to requirements close to those that were already common in voluntary green building certification standards. In the case of Spain, the national regulation in force, CTE DB-HE, the latest version of which dates from December 2019, applies a large part of the solutions first made popular by private certification schemes, such as superinsulation, reduction of thermal bridges or strongly favoring the installation of heat-recovery ventilation systems (MVHR) in some climate zones, even if there is still only indirect control of building envelope airtightness [26,27], and it is considered by many to be on par performance-wise with Passivhaus certification. A recent study in Seville [28] stated that, "*After comparing the specifications of the CTE and PH* [Passivhaus], *it is observed that the health and energy-saving requirements of the mandatory Spanish regulations (CTE) are equal to, or even more restrictive than the PH standard.*" Furthermore, it also stated that, " ... *the application of the PH* [Passivhaus] *standard does not result in a competitive advantage in terms of improvement in energy behavior and building sustainability in a warm climate when compared to the application of passive design criteria based on compliance with current Spanish regulations*".

This has not always been the case, though. The first regulations mandating the insulation of buildings appeared in cold, northern regions, where extreme temperatures could severely affect public health [29]. The first requirements appeared during the First and Second World War, and involved the introduction of simple insulation in the form of double-layer walls with an air cavity or double-layer floors of timber joists. Most European countries developed energy efficiency regulations or building codes after the 1973 oil crisis, although at the time it was associated with "security of oil supply" [30]. This is the case for the United Kingdom in 1972 [31], France in 1974 [32], Italy in 1976 [33] and Germany in 1979 [34].

The first decree regulating the maximum allowable U-values of the building envelope and other energy-saving measures in Spain dates back to 1975 [35], when the country was still under the Franco regime [36]. The much better known NBE CT-79 [37] standard of 1979 remained in force until 29 September 2006, for more than 27 years, and it only covered the building envelope. A much needed, ambitious new building code, the *Código Técnico de la Edificación (CTE)* was approved in 2006 [38] and its Basic Document DB-HE set the new minimum requirements for the building envelope and an upper limit for the energy demand of buildings, in addition to minimum efficiency requirements for thermal building services and lighting installations. It also required some amount of renewable-sourced energy for domestic hot water (DHW) production in the case of housing, which made the code known internationally for strongly encouraging, if not mandating, the use of solar panels [39]. In addition to CTE, since 2007 [40] Spain has had the *Reglamento de Instalaciones Térmicas en los Edificios* [41] (Regulation of Thermal Installations in Buildings, RITE) which is how Spain partially transposed the European Energy Efficiency Directive of 2002 [42]. The objective of RITE is to stablish the energy efficiency requirements for active heating and cooling systems in buildings.

CTE DB-HE was revised in 2013 [43] to include a new section, HE 0, that limits the non-renewable primary energy consumption of buildings. RITE was also revised in 2013 [44] to comply with the new European Energy Efficiency Directive of 2010 [45]. CTE DB-HE was updated again in 2019 and maintained the previous structure, but its calculation methodology was adjusted to European standards and the existing set of indicators was completed with the addition of a total primary energy consumption limit, a new factor for solar gain control ($q_{sol,jul}$), and an indirect control of airtightness, with optional blower door tests. The last update of the Basic Document on Energy Saving (DB-HE 2019) of the CTE advanced the definition of nearly zero energy consumption buildings (nZEBs) as buildings with a very low energy consumption that is covered, to a large extent, with energy from renewable sources. As of today, the current legal definition of a nZEB in Spain is that, new or existing, it complies with the regulatory requirements set out in the Basic Document DB-HE of 2019. This definition is applicable to new buildings and also existing ones when sufficient renovation interventions are carried out. Thus, on average, residential buildings may not consume more than 60 kWh/m^2 of total primary energy and 30 kWh/m^2 of non-renewable primary energy per year [7], although the requirements differ depending on the climate zones [7].

The evolution of energy efficiency regulations in Spain described in this section is summarized in Figure 1. It is important to mention that the progressive tightening of regulatory requirements since the introduction of CTE in 2006 has been guided by cost-optimal calculations [46] for both residential and non-residential buildings in all climatic zones, as foreseen in the Energy Performance of Buildings Directive [45].

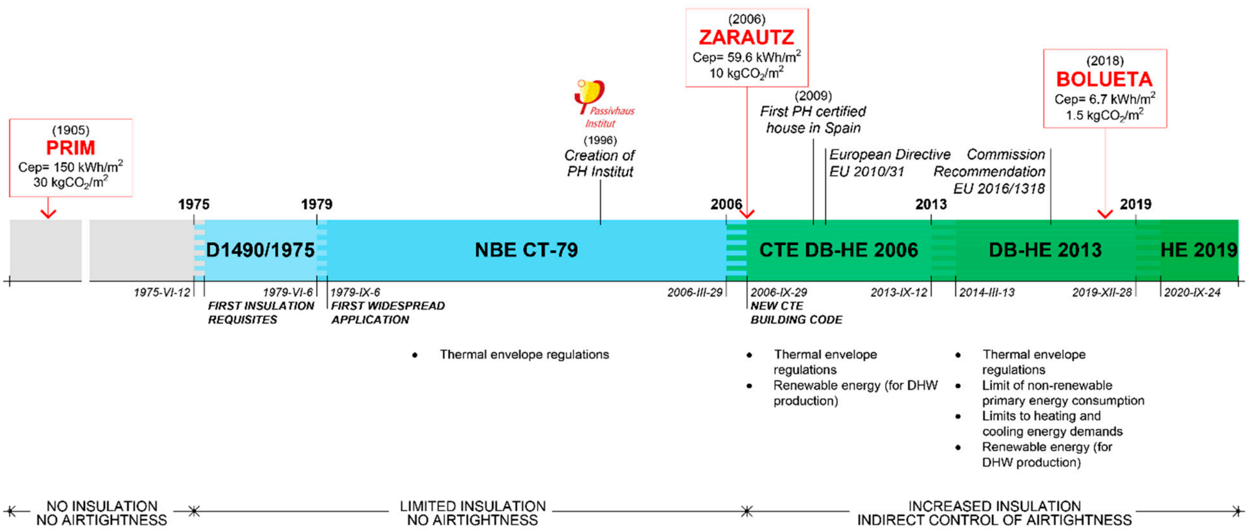


Figure 1. Evolution of the national energy efficiency regulations in Spain. The striped areas show the period of optional/voluntary application of the standards. The figure also shows some milestones of the implementation of the Passivhaus standard in Spain and places in time the case studies that are described in Section 2, summarizing their nominal primary energy consumption and CO_2 emissions. Source: authors.

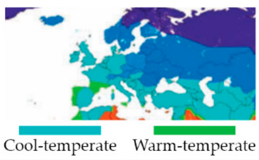
1.3. Implementation of Private Green Building Certificates in Spain and Associated Challenges

Simultaneously with the national standard evolution, civil society's commitment to sustainability has led to a greater demand of nZEBs and, ultimately, to the adoption of several voluntary certification seals such as the ones mentioned in the introduction. In Spain, the most successful private label has been Passivhaus with 255 certified projects published in the PH Database [47], 35 (13.7%) of which are collective housing, and many more are in the process of design and construction. Furthermore, the Passivhaus platform in Spain declares 875 certifying partners [48], which gives an idea of the success of the PH standard in this country.

Even if the Passivhaus Institut was founded in 1996 [49], the standard did not arrive in Spain until 2009, when the first certified building, a single-family house, was constructed in Moraleda de Zafayona, Granada [50]. Over the next 12 years, at least 255 buildings were certified in Spain under the PH standard, including refurbishments, 26 of which were located in the Basque Country and 21 in the neighboring Navarra. Another 43 were located in Cataluña, 41 in Castilla y León, 38 in Madrid and 20 in Asturias, just to cite the regions where the label has been more popular. In the temperate to hot Mediterranean regions of Valencia, the Balearic Islands and Murcia, there are nine, four and two buildings built under the standard to date, respectively.

At the beginning, Passivhaus was thought of as a design strategy for heating-dominated central Europe, primarily for single-family dwellings. Some of the typical certification criteria for these cases are summarized in Table 1. The ultimate aim of the standard was to reduce energy demand and loads associated with heating. In Spain, passive houses are known by the public and are usually perceived in the market as high-efficiency, sustainable homes with a 4–5% cost premium [28]. In Germany, this premium was estimated to be between 3% and 8% in 2013 and 15–20% in the UK in 2014 [51].

Table 1. Summary of the main Passivhaus certification criteria for cool-moderate climates (e.g., London, Paris, Vienna, Rome, Budapest, Istanbul, Beijing, Seoul, Tokyo, Tehran). Adapted from [52].



Certification Criteria (Residential)	Cool-Moderate Climate
Specific Heating Demand	$\leq$15 kWh/(m^2 a)
(or) Specific Heating Load	$\leq$10 W/m^2
Specific Total Primary Energy Demand	$\leq$120 kWh/(m^2 a)
n50 Airtightness at 50 Pa	$\leq$0.6 h^{-1}
Overheating Frequency	$\leq$10% Operative Temperature $\geq$ 25 °C

Passivhaus is frequently advertised as a marketing device in high-end housing developments, and recently, some regional governments have adopted the standard for public sponsored housing. This is the case of Nasuvinsa, a state-owned enterprise for the development of social housing in Navarra that has joined the local Passivhaus consortium [53], and its program, *Navarra Social Housing: a commitment of the government of Navarra for social rental and sustainable energy building*, that will result in the development of 524 social rental units, all of which will be certified under the Passivhaus standard [54], 138 of which have already been finalized in Entremutilvas, Erripagaina and Ardoi [55]. Visesa, the public company dedicated to social housing in the regional government of the Basque Autonomous Community, developed a 27-storey social housing Passivhaus-certified tower with 171 units [25]. A second phase of the same project added another very similar 190 fixed-price dwellings that were, finally, not certified [56].

The Passivhaus design method is founded upon the principles of superinsulation, thermal bridge-free detailing, high airtightness and heat-recovery ventilation systems (MVHR), along with the use of energy-efficient appliances and lighting [57].

One of the biggest concerns about the Passivhaus is a greater perceived risk of overheating compared to less insulated homes. Several studies have investigated the issues related to the betterment of the performance of the building envelope without taking into account the local climatic, typological and social differences between regions [13–21,58,59]. To further advance knowledge in this area in Spain, two studies were carried out in the first Bolueta Tower [23,24]. Additionally, numerous studies deal with mitigation measures in this type of building, but without necessarily clarifying what the alternative roadmap for nZEBs in Spain should be [60–63].

1.4. Literature Review

Chvatal and Corvacho [59] pointed out that better insulation can increase or decrease overheating and that this is more dependent on solar gains and also stress, since overheating has consequences in terms of increased energy consumption. Mavrogianni et al. [64] pointed out that in some cases, increased insulation can lead to overheating. Porrit et al. [65] drew similar conclusions, namely, that increasing insulation thickness can lead to both an increase in overheating and a decrease. Beizaee et al. [66] were more specific, stating that houses built after 1990 overheat more than those from earlier periods. Lomas and Kane [67] pointed out that buildings with load-bearing walls, regardless of their year of construction, are cooler than those built from the 1980s onwards with the introduction of building insulation. McLeod et al. [16] clearly related the increase in insulation to overheating and signified the importance this will have with the predicted climate change. Another article by Mavrogianni et al. [68] studied the performance patterns of users, especially in the case of energy efficient retrofits. Taylor et al. [69] related outdoor climate to overheating in retrofit cases. Van Hoof et al. [70] directly related decreasing U-values to increasing overheating. Gupta and Kapsali [71] pointed out the increase in overheating in energy efficient buildings with installations. Makantasi and Mavrogianni [72] related the effects of insulation with other design aspects to describe the increase in overheating. Sameni et al. [14] reviewed overheating in dwellings through extensive monitoring, but did not advance the causes. Mulville and Stravoravdis [73] pointed out that increasing the efficiency of the envelope, through both insulation and airtightness, increases the problems of overheating.

However, this is a complex issue and it is not yet well-defined which parameters most affect this situation. The most recent studies suggest that good design, good protection against solar radiation at times when it is necessary and good heat dissipation with passive ventilation techniques can make buildings comfortable and in line with the reduction of energy consumption demanded by society and institutions [74].

Most of these studies originated from the UK, a country with a high level of concern about the problem and with a wide range of regulations focused on reducing the impact of overheating in buildings, both in dwellings and tertiary buildings. However, most studies focused on low-density typologies, including single-family and terraced houses. In Spain, most of the population live in collective housing buildings [24]. This has a strong impact on the increase in overheating as we find that, with difficulty in managing ideal orientations, there is greater complexity in achieving correct cross-ventilation and a strong impact of centralized energy installations in compact dwellings. All these factors, if poorly managed, can lead to catastrophic overheating effects.

In general, we understand that these studies show that a bad translation of the Passivhaus/nZEB concept to a different climate and society from the original of central and northern Europe can generate problems in indoor comfort. It is also shown that the best way to detect the problem is to carry out surveys among users, an issue that is often omitted in the Spanish building industry due to the lack of habit of monitoring finished buildings. This can lead to problems that affect the satisfaction of the inhabitants and is reported in the media as a lack of understanding of the problem of overheating [75].

This lack of understanding of the phenomenon of overheating used to be totally foreign and unheard of in the climate of coastal northern Spain (except under uninsulated roofs, at specific times in the summer). In this sense, this study seeks to demonstrate, through a comparative analysis with dwellings built under less strict energy regulations, that overheating is a problem that grows with the current nZEB and Passivhaus trends and will continue if other measures are not taken that clearly facilitate its mitigation; for example, adequate shading and real cross-ventilation.

2. Materials and Methods

This section describes the methodological approach of the study, and describes the analyzed case studies, compares climatic data, presents the materials used for data collection in the monitoring campaign and describes the utilized comfort criteria.

2.1. Description of Case Studies

Three case studies were selected from the coast of the Basque Country that correspond to different periods, representing an evolution in terms of the thermal characteristics of the building envelope. The locations of the case studies and the weather stations utilized in Section 2.3 are shown in Figure 2.

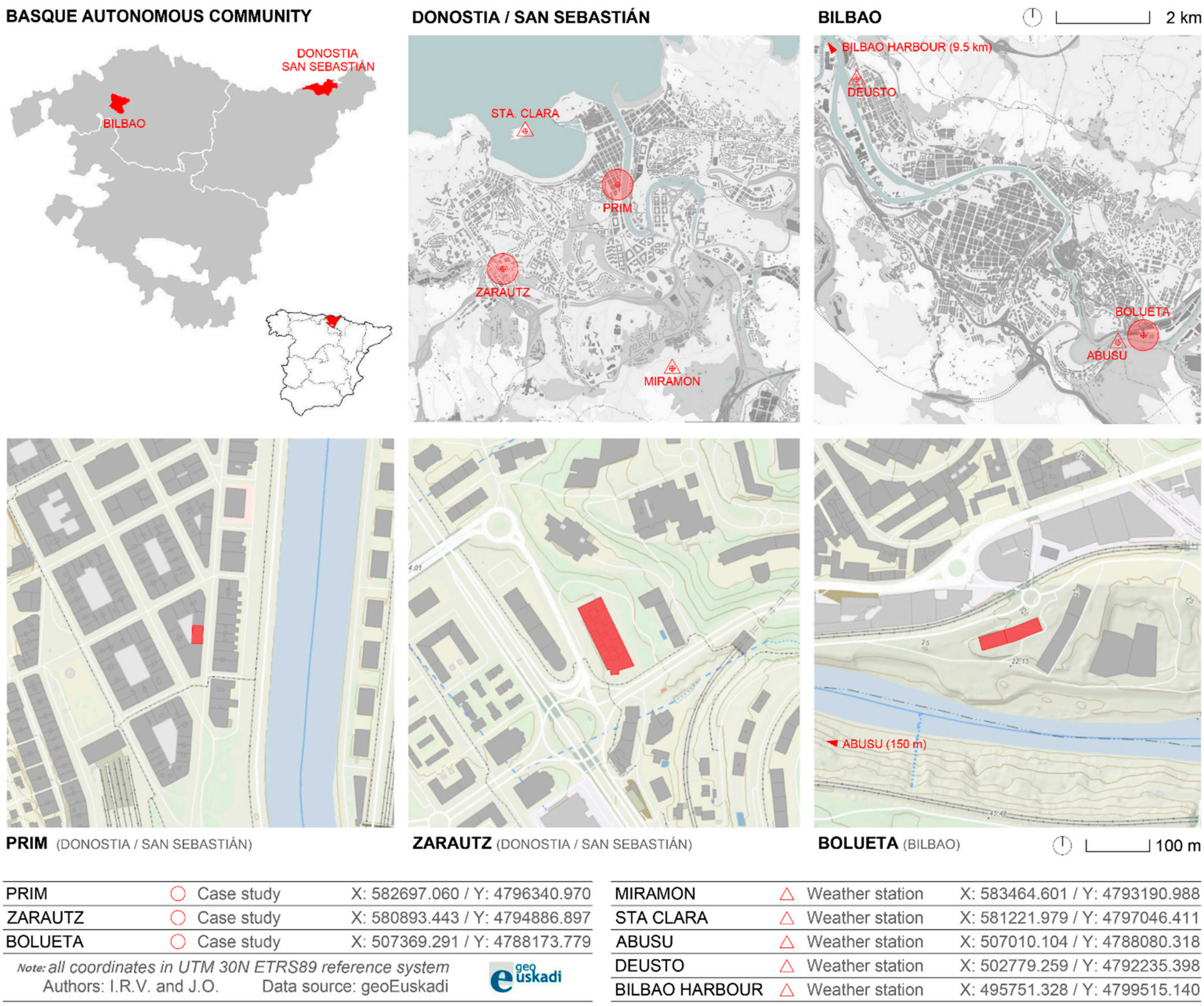


Figure 2. Location of the case studies and meteorological stations used in this study, in Donostia-San Sebastián and Bilbao. Source: authors. Original images were obtained from geoEuskadi, public SIG service of the Basque Country.

The first building was built prior to any thermal regulation, the second building was designed in 2005 under the pre-CTE guidelines of energy consumption reduction and the third building was built under the nZEB criteria using the Passivhaus standard.

The first building is a historic private development, whereas the last two were developed by the Public Housing Company of the Basque Country (Visesa), and therefore, are under the Public Housing Design Ordinances. The case studies are referred to in this paper as Prim, dating from the beginning of the 20th century (ca. 1905) and located in San Sebastian, Zarautz, from 2006 and located also in San Sebastian and Bolueta, located in Bilbao and built in the year 2018. In the latter, 3 dwellings with different degrees of overheating were selected according to the results of [24] and were used here for comparison with the other two flats of Prim and Zarautz.

2.1.1. Flat 1: Prim

The Prim flat is located in the 19th century *Ensanche* (extension) [76] of the coastal city of San Sebastian. It is a house built before any thermal regulation existed, circa 1905. The house is located on the first floor, with the orientations specified in Figures 2 and 3.

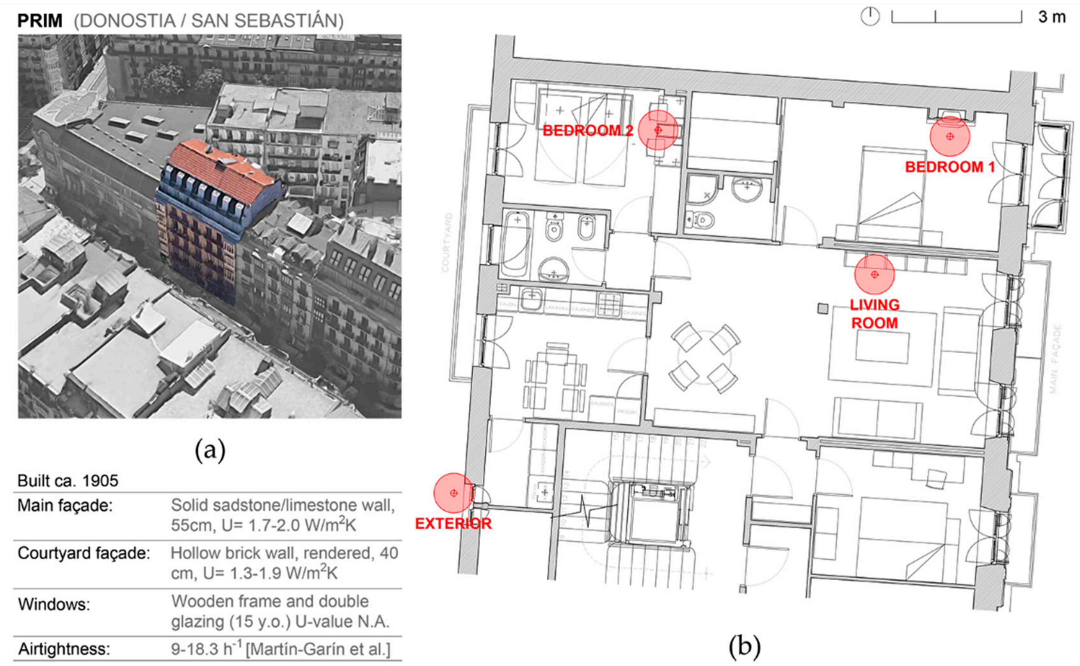


Figure 3. (**a**) Aerial perspective of the Prim building. Source: Google Maps. (**b**) Floorplan of the monitored flat, with indication of the dataloggers' locations. Source: authors.

This building presents the typical construction methods of the mentioned *Ensanche*, with a combination of limestone and sandstone solid walls for the main, street-facing façade and hollow brickwork walls to the courtyard. The floors are built with timber beams and joists, and finished with pine wood flooring and plaster ceilings. During the last renovation 15 years ago, no insulation was added but the original windows were replaced with modern wood frames and double-glazing. The monitored flat still has the original, exterior window shutters which allow for simultaneous shading and ventilation. Balconies with a depth of 60 cm provide additional solar protection. The main bedroom has a mostly glazed bay window that acts similarly to a Trombe wall during winter, but can be fully ventilated in the summer to prevent excessive heat from entering the interior.

The building was not yet tested for airtightness. According to the EN 13465 standard, for buildings constructed before 1940, a level of air tightness of n50 = 9 h^{-1} should be considered. A study on buildings from the same period in San Sebastián [77] studied 4 properties and 9 dwellings in total with similar characteristics to the Prim one, and showed n50 results between 5.69 h^{-1} in the best case and 18.26 h^{-1} in the worst scenario.

2.1.2. Flat 2: Zarautz

Apartment 2 is located in a block of flats built prior to the appearance of the first thermal regulation in the Technical Building Code. However, the characteristics of its envelope can be considered superior to the minimum ones in this standard. All buildings promoted by the Basque Public Administration at that time were subject to more demanding design requirements for the thermal envelope than those mandated by the national standard, NBE CT-79, and were tested and certified by the Basque Energy Agency (EVE). This building was awarded a class A energy rating. The building is located in a peripheral city environment, with formal characteristics typical of public housing, such as openings limited to 10% of the surface area of the rooms, an absence of balconies (except for the first floor) and solar protection by means of exterior blinds, as shown in Figure 4. It is made up of 152 dwellings, 104 public housing units and 48 social housing units of similar characteristics, generally with cross-ventilation between the exterior façades and a large internal courtyard.

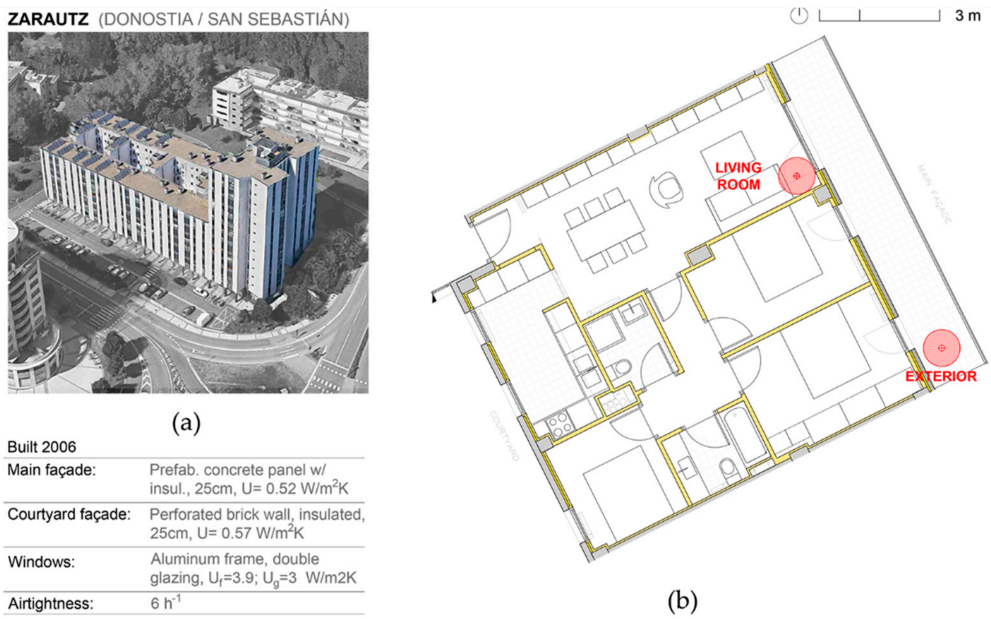


Figure 4. (**a**) Aerial perspective of the Zarautz building. Source: Google Maps. (**b**) Floorplan of the monitored flat on the first floor, with indication of the dataloggers' locations. Source: authors.

The construction characteristics are summarized in Table 3. It is also a typical construction with a reinforced concrete structure, prefabricated concrete façade panels and lightweight plasterboard partition walls. This construction system is widely used in the Basque Country in public housing due to its low cost and speed of execution.

As far as the airtightness of the building is concerned, it must be taken into account that this building was designed without a mechanical ventilation system. The building is ventilated through the infiltration of the building envelope and ventilation ducts in kitchens and bathrooms, fitted with a fan at the end of the shafts in the roof of the building.

However, the building was tested by means of a blower door test, first with said ventilation ducts blocked and then with the ducts open according to ISO/DIS 99721. The average infiltration rate of a typical dwelling, and thus the number of air changes per hour under normal winter conditions, was estimated using the LBL calculation method (from the Lawrence Berkeley National Laboratory, University of California), developed by Max H. Sherman in 1984. From this test, an average air exchange rate of 0.28 per hour was determined, which corresponds to an approximate n50 test of 6 h^{-1} at 50 Pa. This value was considered to be the optimum in these developments as at least some level of infiltration was necessary to facilitate ventilation by means of forced draught at the top of the ducts on the roof. This system was an evolution of the typical *shunt* [78] construction used previously, before the CTE of 2006, and can be considered a form of hybrid ventilation.

2.1.3. Flats 3, 4 and 5: Bolueta Low, Medium and High

The other three studied dwellings are located in Bilbao. They belong to a public development that is between 9 and 27 floors in height and houses 171 flats in total, 63 of which are destined to be subsidized social rental units and another 108 to be VPO fixed-price sale units. The homes were finished in 2018 and occupants could move in after March 2019. The building obtained the Passivhaus certificate in March of 2018. The studied flats are shown in Figure 5. A complete, typical floorplan of the project is available in [24].

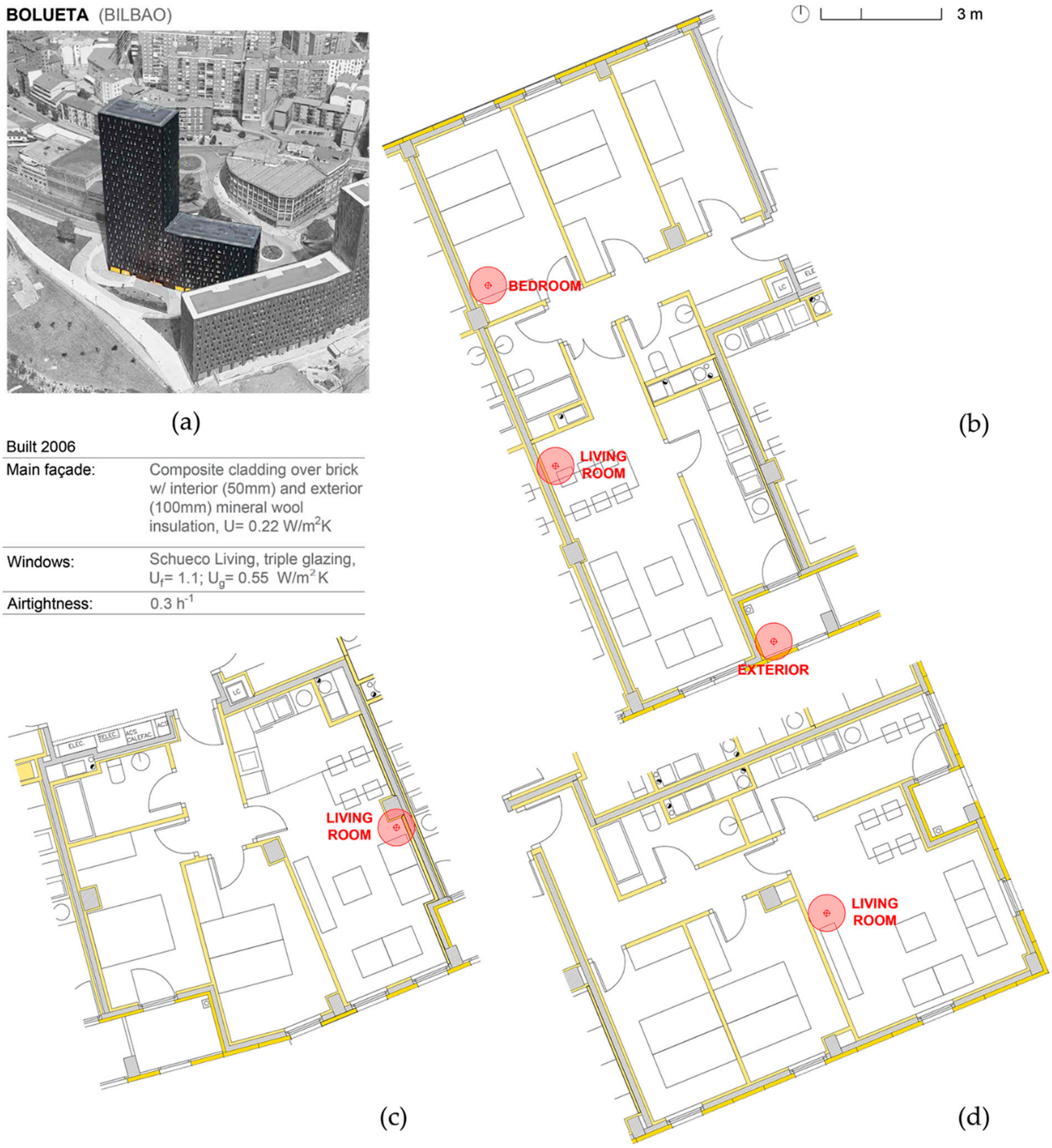


Figure 5. (**a**) Aerial perspective of Bolueta Tower 1. Source: Google Maps. (**b**) Floorplan of the monitored flat Bolueta Low. Drawing (**c**) corresponds to Bolueta Medium and (**d**) to Bolueta High. Note the indicators of datalogger positioning. Source: authors based on as-built documentation.

The tower was constructed with a concrete structure of columns and flat slabs. Façade walls were made of brick with two layers of insulation, one to the inside (50 mm) and another one to the outside (100 mm). The façades were then covered with a black-finish aluminum composite façade panel with varying inclination. Interior partitions were made mostly of lightweight gypsum board partitions. Windows were triple-glazed and protected from direct solar radiation by opaque reflective blinds located in the inside only. The building lacks balconies or any other kind of exterior shading.

The Bolueta Tower was monitored since March 2019 [24]. For this comparative study, 3 dwellings were selected to show the range of overheating of the dwellings, from the least overheated, which we called Bolueta Low, to a dwelling that suffers average overheating, which we called Bolueta Medium, and to a dwelling that shows very high levels of overheating: Bolueta High.

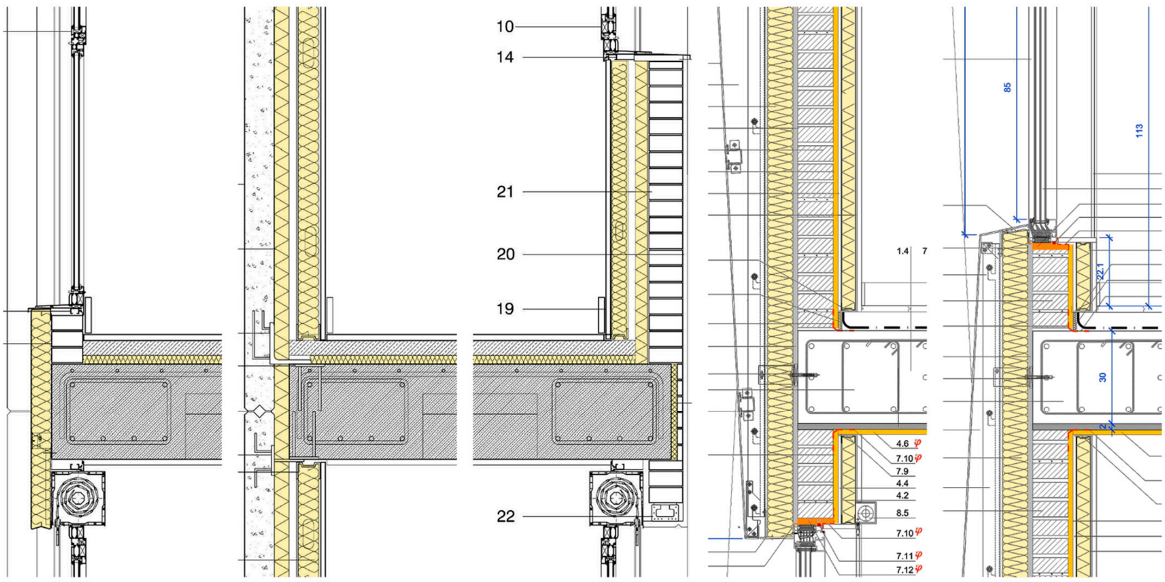
In order to provide a quick reference, some of the main characteristics of the studied buildings are summarized in Table 2.

Table 2. Summary of characteristics of the studied dwellings.

Flat		YoC [1]	Floor Area	Occupation	Orientation [2]		Glazed Area	Shading System	Cross-Vent. [3]
Prim		1905	106 m^2	4 adults/26.5 m^2/pp	Two	E-W	10.7 m^2	Shutters	Opposing fac.
Zarautz		2006	74.9 m^2	2 adults/37.45 m^2/pp	Two	E-SW	9.9 m^2	Ext. Blinds	Opposing
Bolueta	Low	2018	81.8 m^2	3 adults/27.27 m^2/pp	Two	NW-SE	10.8 m^2	Interior Roller Screens	Opposing
	Med.		54.5 m^2	2 adults/27.25 m^2/pp	Mono	S	4.6 m^2		No
	High		68.6 m^2	1 adult + 1 child/34.3 m^2/pp	Two	E-SE	7.7 m^2		Corner

[1] Year of construction. [2] Orientation according to CTE DB-HE [7]. [3] Cross-ventilation: opposing façades, no cross-ventilation due to being mono-oriented or "corner" when façades are at an angle.

Figure 6 compares the façade solutions in the Zarautz and Bolueta developments. The evolution of insulation habits and detailing in the 2006–2018 period can be appreciated. Typically, Spanish exterior roller blinds can be seen in Zarautz, whereas they have been substituted for interior screens in Bolueta, probably to reduce thermal bridging.



(a) (b) (c) (d) (e)

Figure 6. Vertical section detail comparison between the Zarautz and Bolueta case studies. (**a**) shows the slab-facing detail in the fenestration bands of the main façade in Zarautz, whereas (**b**) corresponds to the opaque section of the same façade and (**c**) shows the courtyard façade solution. Adapted by the authors from the Executive Project by SATIE Arquitectos. (**d**) and (**e**) show the equivalent details in Bolueta Tower 1. Adapted by the authors from the Executive Project by VArquitectos.

An overview of the most relevant constructive element properties of the developments are compiled in Table 3.

Table 3. Summary of constructive elements' properties of the analyzed buildings.

Flat	YoC [1]	Walls [2]		Windows			Airtightness n50	Partitions
		$U_{façade}$	$U_{courtyard}$	U_{frame}	U_{glass}	g		
Prim	1905	1.7–2.0 [3]	1.3–1.9 [3]	N.A.	N.A.	N.A.	9–18.3 h^{-1} [77]	Clay Brick
Zarautz [4]	2006	0.52	0.57	3.90	3.00	N.A.	6 h^{-1}	Lightweight
Bolueta [5]	2018	0.22	Does Not Apply	1.1	0.55	0.57	0.3 h^{-1}	Lightweight

[1] Year of construction. [2] All U-values in W/m^2 K. [3] These values were calculated by the authors. [4] Source of data: Cadem (Grupo EVE), who performed the original energy certification of the as-built project. [5] Data gathered from [47].

2.2. User Comfort Surveys

The Prim dwelling was occupied by a family consisting of a couple and their two children, aged 20 to 30. In the surveys carried out, they did not report day- or night-time discomfort during the summer, except for occasional events during exceptionally hot days in summer. Evidently, this home has a high heating demand in winter, but this is addressed with a natural gas boiler and water-based radiators to avoid discomfort at the expense of energy efficiency in winter.

The Zarautz flat was occupied by a married couple. In the surveys carried out, they did not report any type of discomfort, except for occasional moments during the hottest days of summer, and only during the daytime. In winter, they stated that they only turn on the heating at specific times, and then the house stays above 19–21 °C with no major problems of discomfort.

The Bolueta dwellings were studied by means of surveys (Figure 7) extended to a high proportion of users, which showed a clear problem of summer discomfort both during the day and at night-time [23,24].

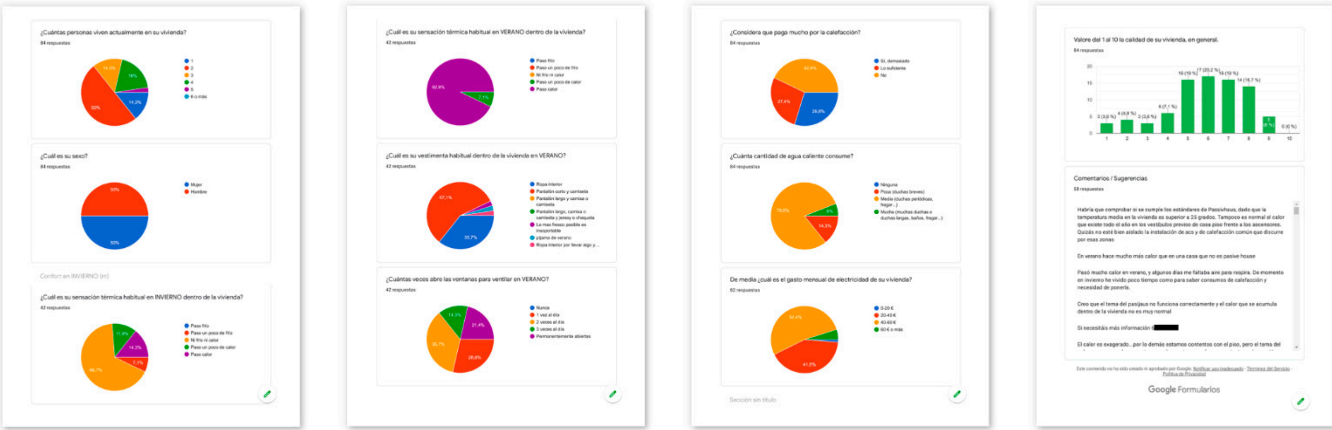


Figure 7. Snapshots of the Bolueta Tower 1 post-occupancy evaluation survey for thermal comfort. Source: authors.

It is common for users to sleep with the windows open to mitigate the heat at night, although depending on the location of the dwelling this generates problems with outside noise and insects in the area due to the presence of a river nearby. In relation to noise pollution, both Prim and Zarautz dwellings are located in a noisy environment during the daytime, due mostly to traffic. This information was first collected via user surveys and then compared to the Donostia-San Sebastián [79] and Bilbao [80] municipal noise maps, both for Lden and Ln metrics (Figure 8). As declared by the Bolueta residents in the surveys, a noisy environment interferes with natural ventilation, especially during the night when it can be an impediment for proper sleep.

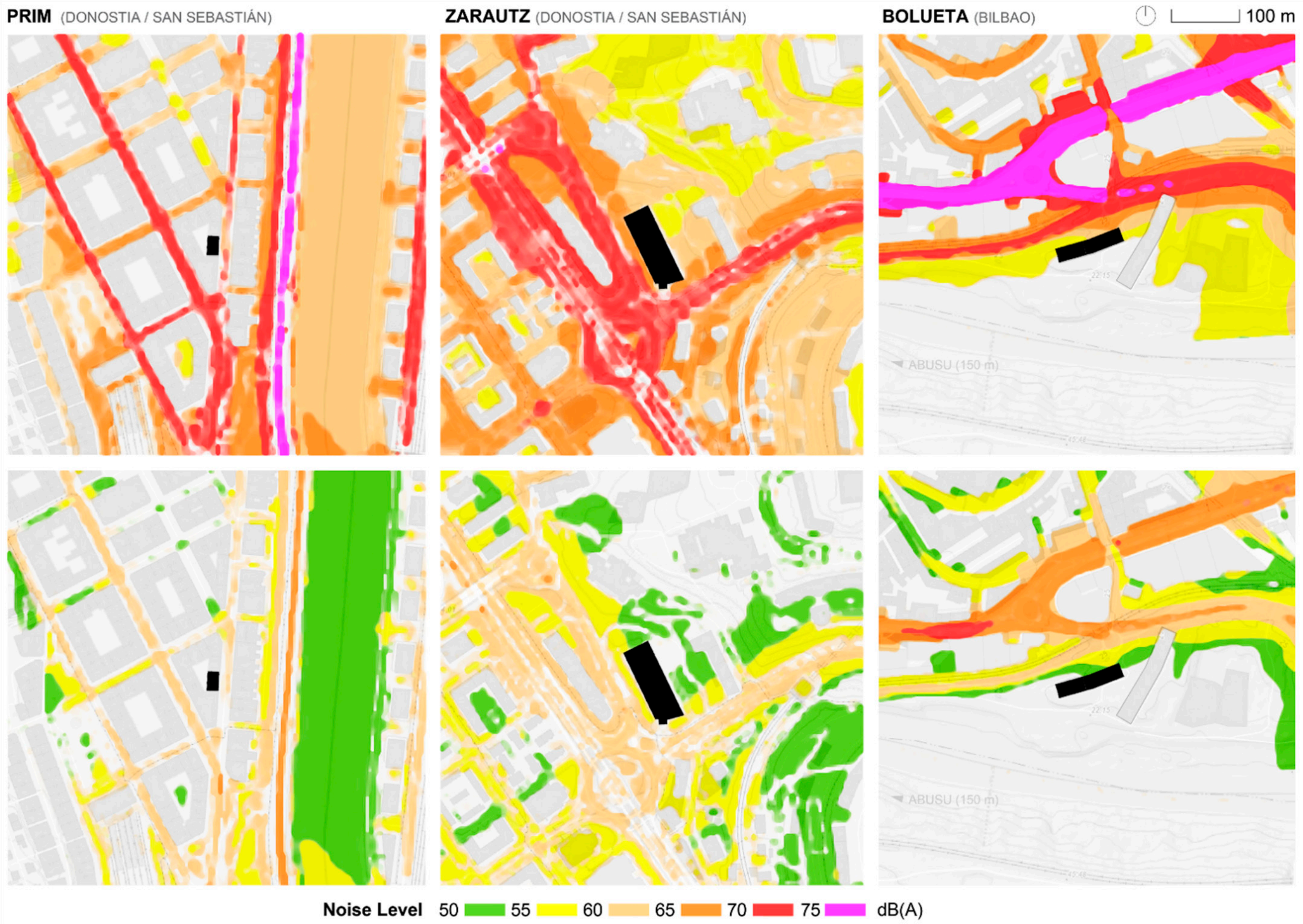


Figure 8. Complete daytime Lden (**top**) and night-time Ln (**bottom**) noise levels in the surroundings of the studied buildings, according to the Donostia-San Sebastián and Bilbao local noise maps. Source: authors, adapted from [79] and [80].

The user surveys also surfaced the problem of simultaneous natural ventilation and bedroom darkening in the Bolueta Tower, as the interior blinds do not allow for the windows to be open at the same time.

2.3. Data Collection

To perform the monitoring, commercial-grade datalogger equipment from T&D was used. All equipment was factory calibrated previous to the installation. T&D RTR-576 devices with three channels (temperature, relative humidity and CO_2 concentration) were used for monitoring in some cases (see Figure 9), preferably in bedrooms. For RTR-576, the measuring range of CO_2 was 0 to 9999 ppm, temperature was 0 to 55 °C (accuracy ±0.5 °C) and humidity was 10% to 95% RH (accuracy 5% RH at 25 °C, 50% RH). To collect the data, the readings were transmitted via FTP using T&D RTR-500 base units. In the rest of the cases, T&D TR-72wb dataloggers were used, which take temperature and RH readings only. The accuracy declared by the manufacturer was the same as the RTR-576. A more detailed description of the equipment used is available in [24]. All sensors were installed at the approximate height of one meter, avoiding direct sunlight or other heat sources (radiators, appliances, etc.). An approximate location of where each monitoring device was placed can be seen in Figures 3–5, whereas the monitored dwellings and periods, as well as some complementary data, are shown in Figure 9.

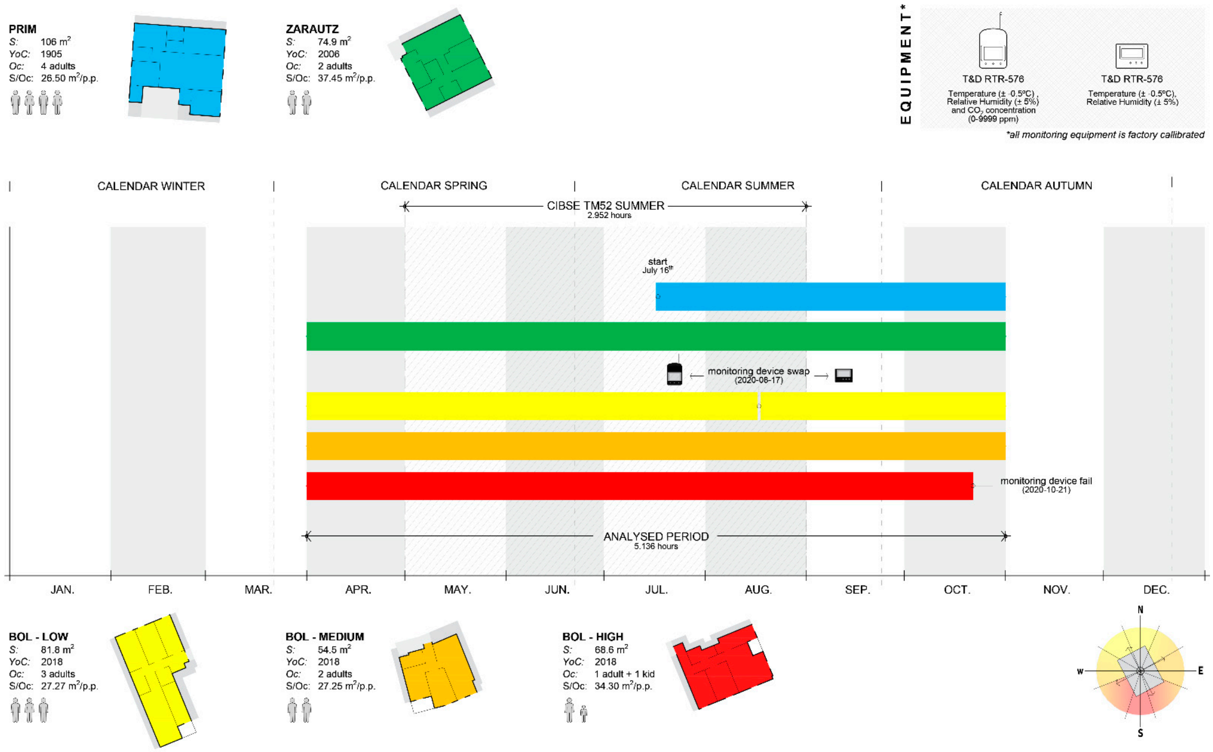


Figure 9. Summer 2020 monitoring campaign overview. Source: authors.

The start and end dates of the monitoring period reported in this paper were motivated by the availability of equipment and the length of the summer. In addition, an extra month was added at the beginning and two at the end of the time usually considered summer, including data from April to October.

In the case of Prim, the monitoring started on 16 July. In the Bolueta Low case study, an RTR-576 datalogger was placed in the living room at the beginning of the study, but it was later substituted with a TR-72wb device, and the RTR-576 was relocated to the bedroom, where its ability to record CO_2 concentration was deemed more useful. In Bolueta High, a device failure on 21 October made the datalogger stop recording.

The dataloggers, whose positions are shown in Figures 3–5, are listed in Table 4 together with their operating period.

Table 4. Summary of monitoring periods in each of the 5 apartments.

Case Study		Room	Reported Monitoring Period
Prim		Living Room Bedroom 1 Bedroom 2 Exterior	16 July–31 October
Zarautz		Living Room Exterior	1 April–31 October
Bolueta	Low	Living Room Bedroom	1 April–31 October 16 July–31 October
	Medium	Living Room	1 April–31 October
	High	Living Room	1 April–31 October

2.4. Thermal Comfort Models

To evaluate summer comfort, a similar approach to [24] was used. In the case of overheating, [81] pointed out that, "*At present there is no robust, defensible and universally accepted definition of overheating either for use in the assessment of proposed dwellings, for example, by modelling, or for as-built evaluation . . . . papers reporting monitoring studies use different criteria to evaluate whether or not overheating has occurred*". In consequence, this paper used various comfort models, both fixed-threshold and adaptative, as summarized in Table 5.

Table 5. Summary of fixed-threshold and adaptative model thermal comfort standards. Retrieved from [24].

Standard	Overheating Criteria
Passivhaus Institut [82]	Limits number of hours T > 25 °C. Max. hours where T < 25 °C: 10%, recommends < 5%. Number of hours T > 25 °C: • >15%, Catastrophic; • 10–15%, Poor; • 5–10%, Acceptable; • 2–5%, Good; • 0–2%, Excellent.
CIBSE Guide A [83]	T_{max} is 25 °C for living rooms and 23 °C for bedrooms. Overheating when T > 28 °C during 1% of year for living rooms and T > 26 °C during 1% of the year for bedrooms.
ISO 7730 [84]	**Predominantly mechanically ventilated buildings** RHmin = 40% and maximum RHmax = 60%: • Category A: Tmin 21 °C, Tmax 25.5 °C; • Category B: Tmin 20 °C, Tmax 26 °C; • Category C: Tmin 19 °C, Tmax 27 °C.
EN 16798-1 [85]	**Predominantly naturally ventilated buildings** • **Category I:** buildings with vulnerable occupants, i.e., elderly citizens: Upper temperature limit, T_{comf} = 0.33 Trm + 18.8 + 2. • **Category II:** other buildings: Upper temperature limit, T_{comf} = 0.33 Trm + 18.8 + 3. When the upper temperature limits according to the categories cannot be guaranteed by passive means, mechanical cooling is unavoidable.
CIBSE TM:52 [86]	**Predominantly naturally ventilated buildings** • **Criterion 1:** hours of exceedance (H_e); • **Criterion 2:** daily weighted exceedance (W_e); • **Criterion 3:** upper limit temperature (T_{upp}). A room is overheated if any two of the three following criteria fail.
CIBSE TM:59 [83]	**Predominantly naturally ventilated buildings** **(a) Living rooms, kitchens and bedrooms:** The number of hours during which ΔT is greater than or equal to a 1 K during the period from May to September will not be more than 3% of occupied hours (CIBSE Criteria TM:52 1: Hours of He Exceedance). **(b) Bedrooms only:** To ensure comfort during sleeping hours, the operating temperature in the bedroom from 10 p.m. to 7 a.m. should not exceed 26 °C for more than 1% of the annual hours (32 h). **Predominantly mechanically ventilated** **Living rooms, kitchens and bedrooms:** Annual hours ΔT > 1 K less than 3% of occupied hours.

The most widely accepted methodologies are the thermal balance or empirical model used in EN ISO 7730:2005 [84] and EN 16798-1:2019 [85], and the adaptative models that account for subjective thermal adaptations of subjects to outside weather such as CIBSE TM:52 [86] and CIBSE TM:59 [83]. In Spain, the technical standard in force to this effect (RITE) [41] is based on EN ISO 7730. As for EN 16798-1:2019, it can be considered to be integrated within the CIBSE technical memorandums TM:52 and TM:59, as they work with the same design targets and adaptative limits, adding three failure criteria for predominantly naturally ventilated buildings:

- The first criterion sets a limit for the number of hours that the operating temperature can exceed the comfort temperature threshold (upper limit of the comfort temperature range) by 1 K or more during the occupied hours of a normal period outside the heating season (1 May to 30 September).
- The second criterion refers to the severity of overheating on any given day, which can be as important as its frequency, the level of which is a function of both the increase in temperature and its duration. This criterion sets a daily limit for acceptability.
- The third criterion establishes an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable.

2.5. Exterior Climate Data Sourcing and Analysis

The local and urban climate is a key parameter in the design of nZEB houses. Solar radiation, outdoor temperature, sky coverage and other climatic parameters are decisive factors in the calculation of the energy balance, thus it is necessary to have verified data. The local climate influences the required transmittance values for façades and window frames and glass, as well as the size and orientation of rooms and the proportion of openings to be provided. This, finally, determines whether the winter or summer period is the most critical when it comes to responding with an appropriate building design. For this study, we analyzed the different statistical climate data and the data collected both by the weather stations and by the outdoor sensors located in the monitored dwellings. Figure 2 shows the location and coordinates of buildings and weather stations in San Sebastian and Bilbao.

2.5.1. Data Sources

With the aim of limiting the energy demand of buildings, the different European directives specify the importance of considering the climatic peculiarities of each territory, and it is the responsibility of each country to establish the procedures and the specific requirements that their buildings must comply with.

In the case of Spain, the determination of climatic zones in the CTE Building Code is based on the calculation of winter and summer climatic severities for locations that have contrasting climatic records. Once the two climatic severities are obtained, the climatic zone of a certain location is determined by composing the winter and summer severities, in accordance with the CTE DB-HE of 2019. The climatic data is available for download from [87].

For the city of San Sebastian, the climatic zone is D1 and for the city of Bilbao, C1. As the two cities have the same summer climatic severity, 1, the climate data used by the standard has the same temperature distribution during the summer. In October, we observed that the climate diverges in the two different climate zones. Figure 10 shows dry-bulb temperature, relative humidity and global horizontal solar radiation for climate zones C1 and D1 in the Spanish Technical Building Code (CTE).

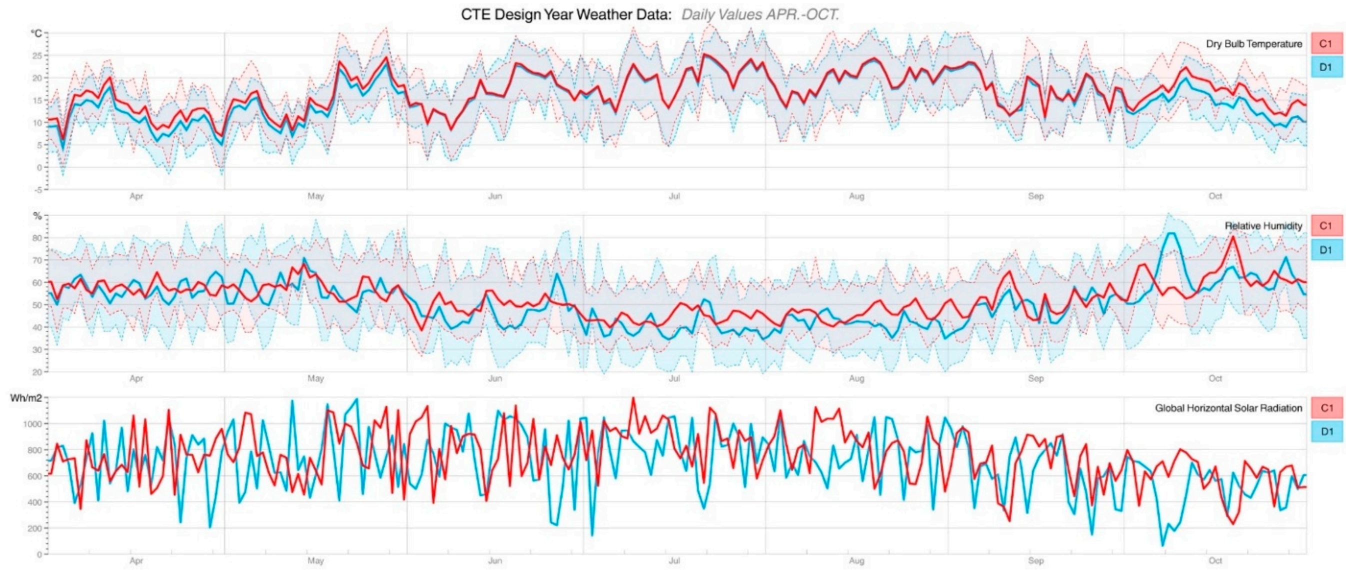


Figure 10. CTE Design Year weather data for climate zones C1 (Bilbao) and D1 (San Sebastian), April to October. Source: authors.

However, the climatic data in the CTE Building Code was prepared for design regulatory purposes in the whole of Spain and, therefore, implies a certain degree of simplification; namely, it does not necessarily perfectly fit the actual climate of a specific location (not all cities and towns under zones C1 or D1 have the same climate, although they might be similar).

It is therefore recommendable to analyze statistical weather data specific to the location of the case studies. TMYx (Typical Meteorological Year) files [88] are typical weather files constructed with hourly data during the 2004–2018 period following the ISO 15927-4:2005 [89] methodology. Analyzing the Typical Meteorological Years, it is possible to see that the San Sebastián and Bilbao climates have some differences that are not reflected in the weather files used by the Spanish regulation (Figure 11). However, the San Sebastián and Bilbao climates are considered similar enough to perform comparative analysis between case studies.

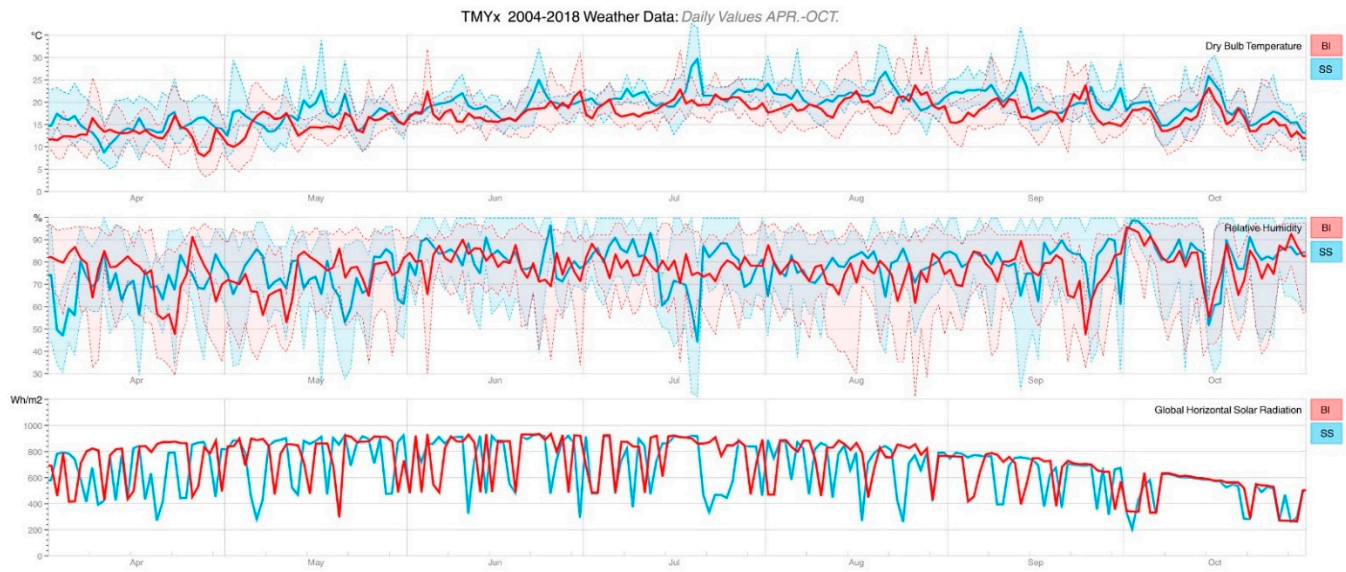


Figure 11. TMYx statistical weather data (2004–2018) for Bilbao (red) and San Sebastian (blue), April to October. Source: authors.

2.5.2. Microclimate Analysis

Climate zone characterizations apply to large territories; however, within these areas and, due to local factors specific to the terrain, particular climatic variations or microclimates will appear with very marked characteristics capable of significantly modifying the boundary climatic conditions [90]. These factors can be summarized for the case of the Basque coast as follows:

- Distance from the sea: it has a regulating effect on the thermal gradient, reducing maximum temperatures and increasing minimum temperatures.
- Altitude: In humid climates, the temperature drops by 0.3 to 0.8 °C. In addition, there is higher solar radiation and higher nocturnal radiation, which increases the thermal gradient.
- Presence of vegetation: it has a similar effect as the sea, preventing overheating of the soil and avoiding nocturnal radiation, and reducing the day–night temperature jump, resulting in a typically cool climate during the day and temperate at night.
- Location: the intricate and mountainous orography of the area in question and its location in relation to the Iberian Peninsula, which is itself a mountainous area with a high average altitude, makes the Basque Country and Navarre a hinge area between the Iberian Peninsula and the Aquitaine Depression, which is therefore influenced by these geographical areas and, although neither of them is the source of air masses, they are of great importance in terms of baric and hydric changes.

At the individual level, the thermal sensation is essential, and at the building level, the design and construction of an efficient project makes the study of the climate and the microclimate fundamental. The components described here speak of the importance of the site. All the components vary the climate.; hence, the difficulty of efficient architectural design. In terms of architecture, the components listed here make the energy performance of a building vary considerably. In the case of the Basque Country, a number of microclimatic effects are well characterized in Figure 12.

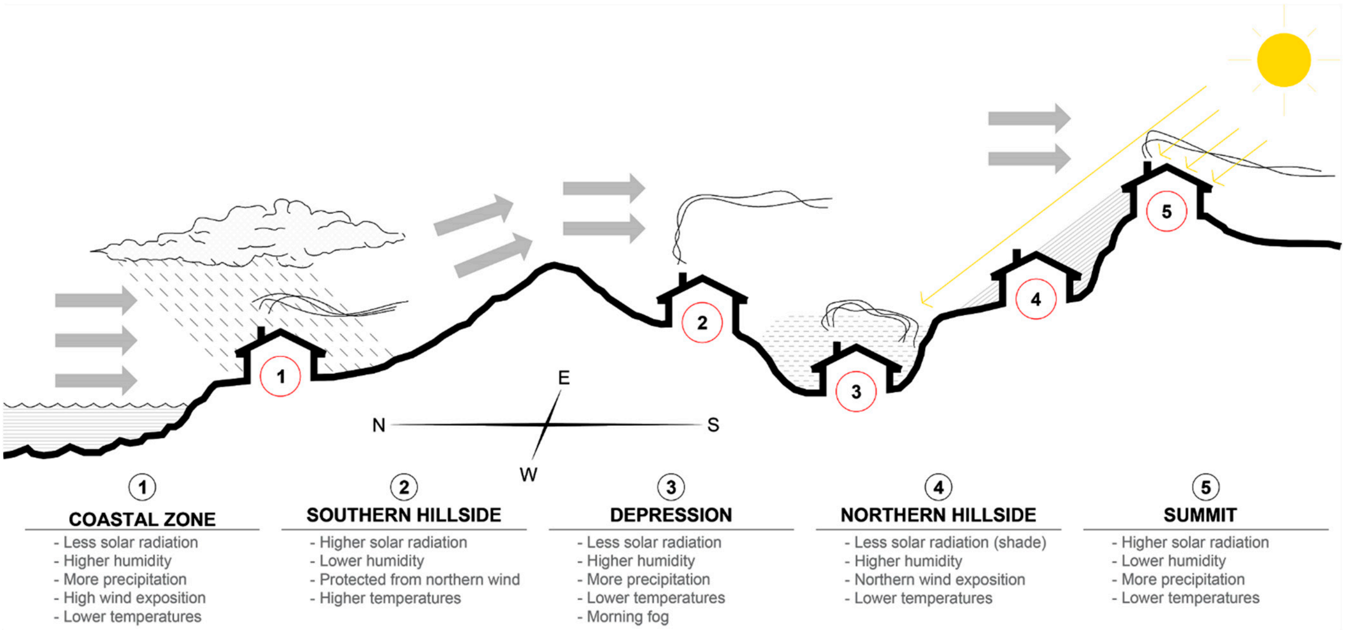


Figure 12. Typical bioclimatic implications of building location in the coastal Basque Country. Source: authors, adapted from [90].

In the specific cases of the cities of San Sebastián and Bilbao, the microclimatic particularities of the cases studied can be observed thanks to the meteorological stations of the Basque Meteorology Agency during the summer of 2020, of which the data obtained from them are shown the following figures. In San Sebastian (data in blue), data from the stations at Santa Clara, which is by the sea, and Miramón, which is on a hill in the interior of the city with greater altitude and solar radiation, were analyzed. In the city of Bilbao (data in red), data from the Bilbao harbor, which is next to the sea, Deusto, which is in the city center, and Abusu, which is near to Bolueta, were analyzed.

On a hot summer day (Figure 13), we observed that daytime temperatures were higher inland in both cities (dashed and solid lines) than on the coast (dotted lines); however, night-time temperatures were lower inland than on the coast. Here, we have a clear temperature regulating effect due to the sea mass. The sea temperature in August on the Basque coast is about 22 °C on average. On 6 August 2020, there was a prevailing southerly wind, which was generally warm due to the foehn effect. Solar radiation was similar at the Santa Clara (San Sebastian) and Deusto (Bilbao) stations, with a peak value of 900 W/m^2 of irradiance. Miramón, Abusu and Bilbao harbor stations did not record solar radiation.

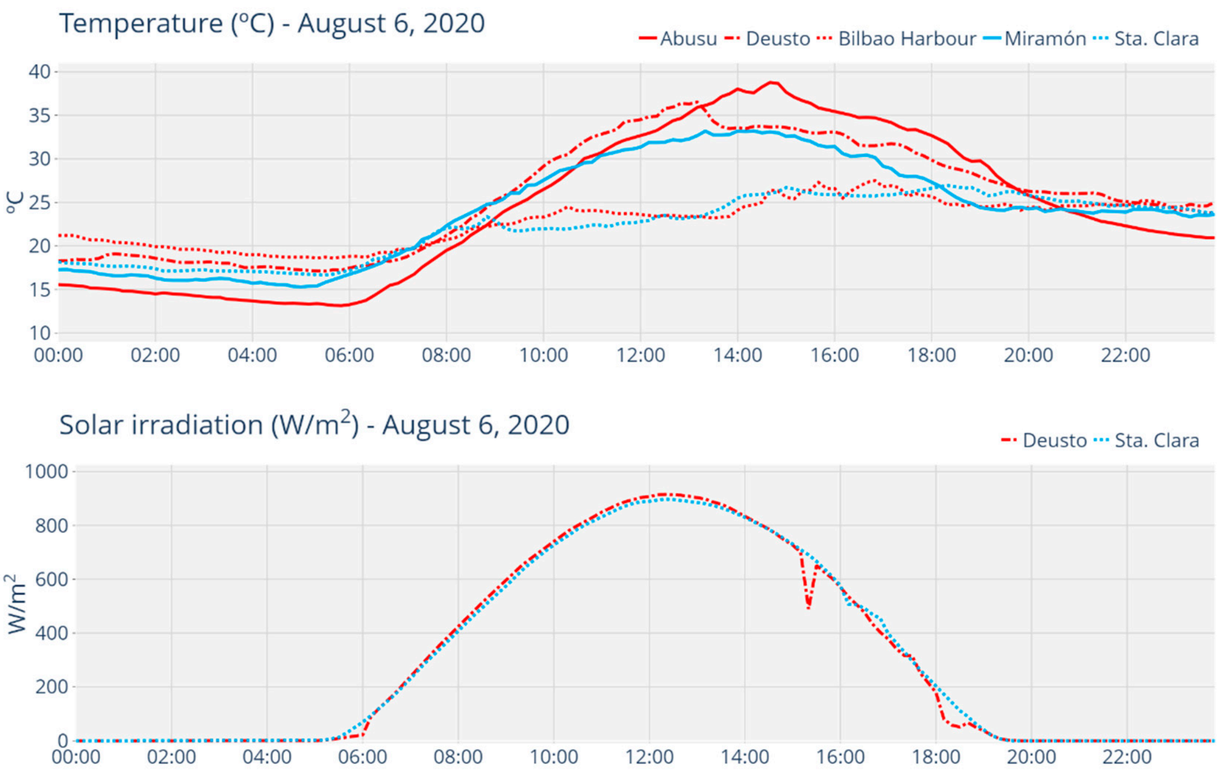


Figure 13. Comparison between recorded temperatures (**top**) and solar radiation (**bottom**) on a clear day in summer (6 August 2020). Source: authors.

If we observe a day in August with cloudy skies and low radiation together with a day that was clearer and had high radiation, such as 28–29 August (Figure 14), we see that the temperatures were higher in the Bilbao stations (red) than in San Sebastian (blue), where temperatures were lower and influenced by a strong northeast wind (up to 40 km/h). At all times, the temperature of the coastal stations is higher than that of the interior due to the attenuating effect of the sea, and we can see that the effect of radiation does not have much influence on the exterior temperatures except to make the interior stations exceed at times the temperature of the stations by the sea.

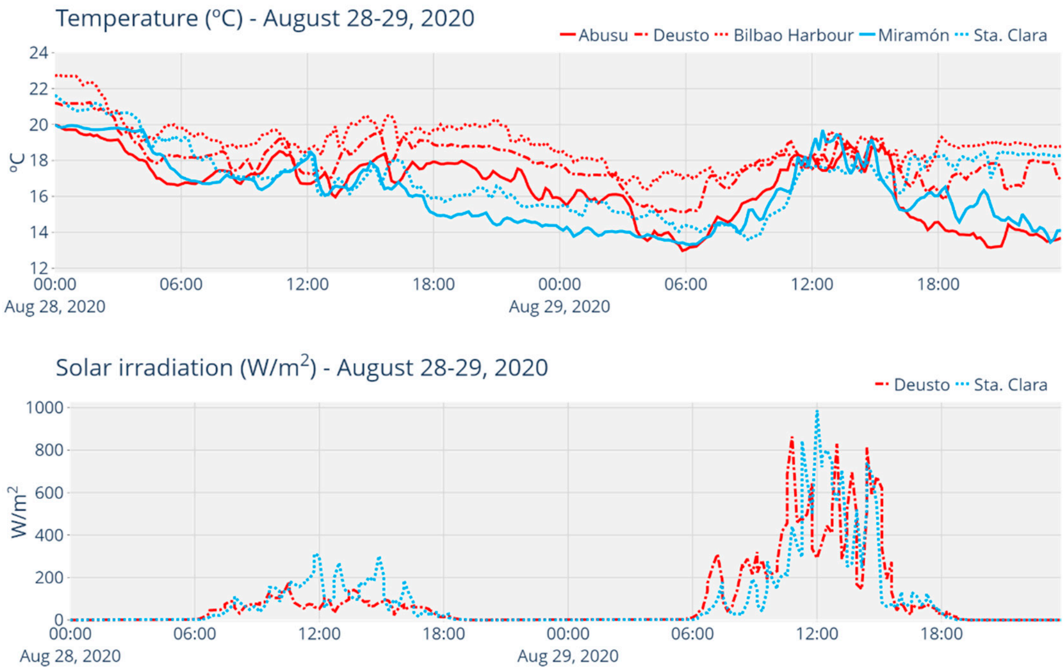


Figure 14. Comparison between recorded temperatures and solar radiation on 28–29 August 2020, on a cloudy day followed by a clear day. Source: authors.

At the end of September there is typically a significant drop in temperatures in this climate. Solar radiation also decreases slightly. The prevailing winds are from the west and up to 40 km/h, and also from the N-NE. The pattern, however, remained the same in 2020 (Figure 15), with higher temperatures in Bilbao, and higher temperatures by the sea than inland.

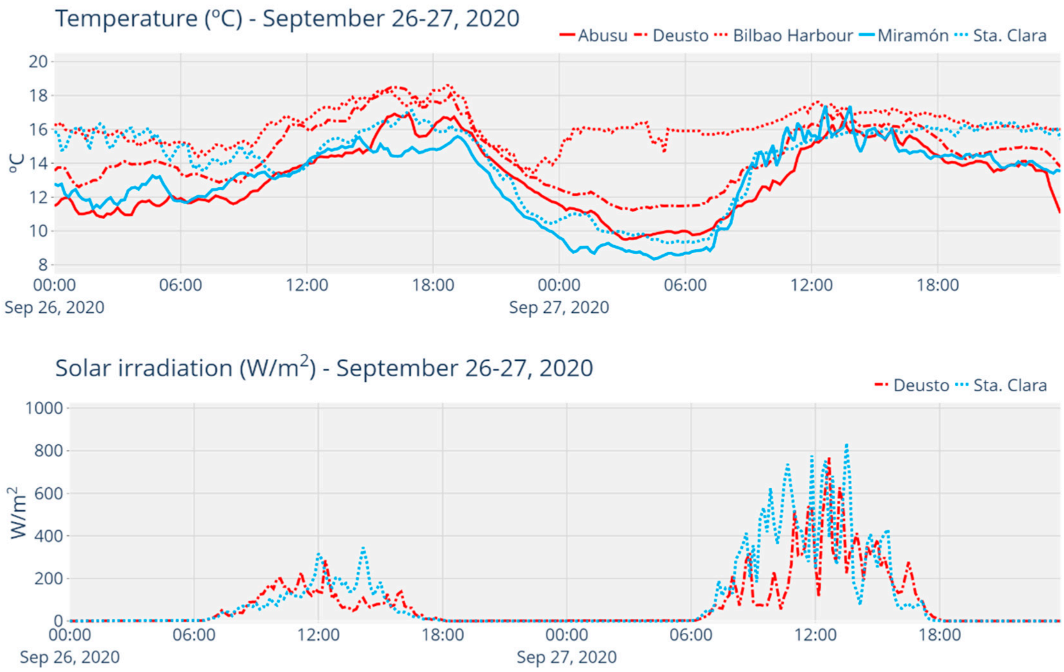


Figure 15. Comparison between temperatures recorded and solar radiation recorded on a cloudy day followed by a clear day in September (26–27 September 2020). Source: authors.

The San Sebastian City Council produced a thermal map using climate data and the UrbClim [91] urban climate model. Figure 16 shows the map for the city as a whole with the resolution provided by the 100 by 100 m grid model.

The UrbClim study shows that, "*The average maximum temperature values for the period analyzed vary between 23.4 and 27.7 °C between some parts of the city and others. The lowest maximum temperature values correspond to the areas close to the coastal strip and higher parts of the city. The maximum temperature increases as the influence of the sea is lost, with the highest temperatures in inland and lower elevation areas. It is worth mentioning that the temperature is slightly lower following the course of the Urumea River, which also acts as a temperature regulator along its course*". This demonstrates the great influence of microclimatic factors on the urban climate and ratifies the data collected in the period studied for the homes located in San Sebastian.

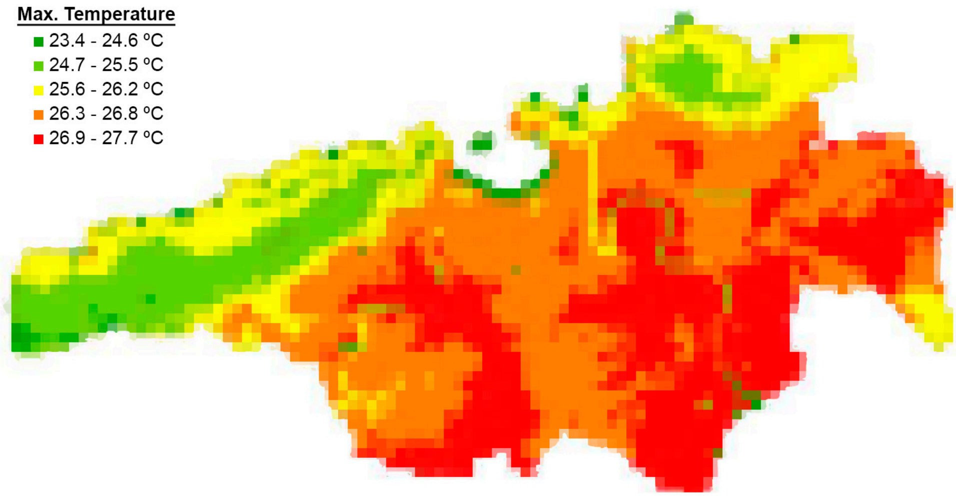


Figure 16. Map of maximum mean temperatures from the UrbClim study, measured in the period May to September 2003 with a resolution of 100 m. Source: UrbClim Donostia-San Sebastian [91].

For this paper, exterior temperature and RH data sources were used as close as possible to the dwellings studied, either with sensors located on the outside of the dwellings themselves or with the nearest official weather stations available. For the adaptative comfort assessment in this study, the following data sources were selected:

- Prim: a sensor located in the façade of the flat, in the shaded courtyard.
- Zarautz: a sensor located on the outside the dwelling.
- Bolueta: Abusu weather station, close to the Bolueta building (see Figure 2). Data collected from the Deusto station in summer 2019 is introduced in Figures 13–15 for comparison, revealing that it was a summer with similar characteristics.

An analysis of the exterior temperature/relative humidity pairs over the comfort model shows that the oldest dwelling, Prim, had typical exterior temperature values similar to those of the Zarautz case study, with peaks of 27.5 °C. The Zarautz dwelling environment had slightly lower values than Prim, probably because it is located in more of a peri-urban environment with a higher presence of green spaces and vegetation in the surroundings.

3. Results

This section presents the results of the monitoring campaign (temperature, relative humidity and CO_2 concentration) and displays the collected data in both graphic and table form, as well as assessing night-time comfort and providing comments to all the presented data.

3.1. Overall Thermal Comfort

A look into the mean monthly temperatures of each of the case studies offers a general idea of the differential performance between each of the dwellings (Table 6).

Table 6. Average monthly temperatures (°C), April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim					24.7 [1]	24.8	23.1	21.0
Zarautz		21.0	22.4	23.4	24.7	25.6	24.5	20.58
Bolueta	Low	23.1	23.4	23.6	25.2	25.4	23.4	22.4
	Medium	24.3	23.4	23.6	24.4	25.2	24.3	23.7
	High	23.4	25.5	26.2	27.2	27.9	26.8	23.3 [2]

[1] Incomplete month, monitoring starts 16 July. [2] Incomplete month, monitoring ends 21 October.

The recorded relative humidity values are presented in Table 7, aggregated into the monthly average per case study.

Table 7. Average monthly relative humidity (%), April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim					6 % [1]	66%	62%	59%
Zarautz		59%	63%	64%	66%	66%	62%	61%
Bolueta	Low	48%	53%	55%	57%	59%	58%	54%
	Medium	44%	54%	55%	58%	56%	53%	48%
	High	47%	48%	49%	51%	52%	47%	49% [2]

[1] Incomplete month, monitoring starts 16 July. [2] Incomplete month, monitoring ends 21 October.

A first quantitative analysis of the hours with values > 25 °C is presented in Table 8. The analysis allows us to quantify the impact of overheating in the different dwellings monitored. On the one hand, it can be seen that the higher the performance of the envelope, the greater the increase in overheating periods. The Zarautz dwelling, with relatively high insulation values, recorded overheating values higher than those required by the Passivhaus Institut; however, this was limited to a very short period of the year, from mid-July to mid-September. Inhabitants of this apartment reported no natural ventilation during a period of 15 hot days in August when they were away from the dwellings.

Table 8. Number of hours where T > 25 °C, April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim					105 [1]	300	77	0
Zarautz		0	1	38	261	594	256	0
Bolueta	Low	8	96	101	449	511	116	1
	Medium	79	127	86	259	453	309	38
	High	16	507	656	744	739	680	2 [2]

[1] Incomplete month, monitoring starts 16 July. [2] Incomplete month, monitoring ends 21 October.

By counting hours > 28 °C, the overheating stress to which dwellings are subjected can be better measured (Table 9).

Table 9. Number of hours where T > 28 °C, April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim					0 [1]	2	0	0
Zarautz		0	0	0	0	0	0	0
Bolueta	Low	0	0	0	5	4	0	0
	Medium	0	0	0	0	3	2	0
	High	x	0	10	97	242	69	0 [2]

[1] Incomplete month, monitoring starts 16 July. [2] Incomplete month, monitoring ends 21 October.

As for the maximum and minimum temperatures recorded during the monitoring period, it is notable that, frequently, the Bolueta Low, Medium and High study cases seemed to have a larger amplitude with higher peaks and lower valleys, as shown in Table 10 and also in Figure 17.

Table 10. Minimum and maximum recorded temperatures (°C) for each of the case studies, April–October 2020.

Case Study		April		May		June		July		August		September		October	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Prim [1]								23.1	27.9	20.6	28.8	19.9	26.2	18.4	23.4
Zarautz		17.3	23.5	20.1	25.4	20.5	25.7	21.5	26.6	21.5	27.5	21.2	26.9	18.0	22.8
Bolueta	Low	20.9	26.2	19.7	26.6	20.2	26.7	20.3°	28.2	20.1	28.7	18.9	28.0	19.8	25.2
	Medium	20.5	27.9	17.5	27.4	17.9	27.1	20.0	27.4	18.9	28.3	17.5	28.6	17.1	26.7
	High [2]	19.8	25.4	23.4	27.8	24.4	28.4	25.4	29.1	24.0	29.3	22.7	29.0	21.1	25.3

[1] Monitoring period: 16 July–31 October. [2] Monitoring period: 1 April–21 October.

Observing the interior evolution of temperatures in the dwellings, some conclusions can be drawn: Older dwellings have lower interior temperatures. The PH dwellings, in order to maintain lower average temperatures, need to carry out important ventilation actions, as observed in the amplitude between daily maximum and minimum temperatures. The Passivhaus-certified apartments with less action on ventilation suffer from much higher indoor temperatures.

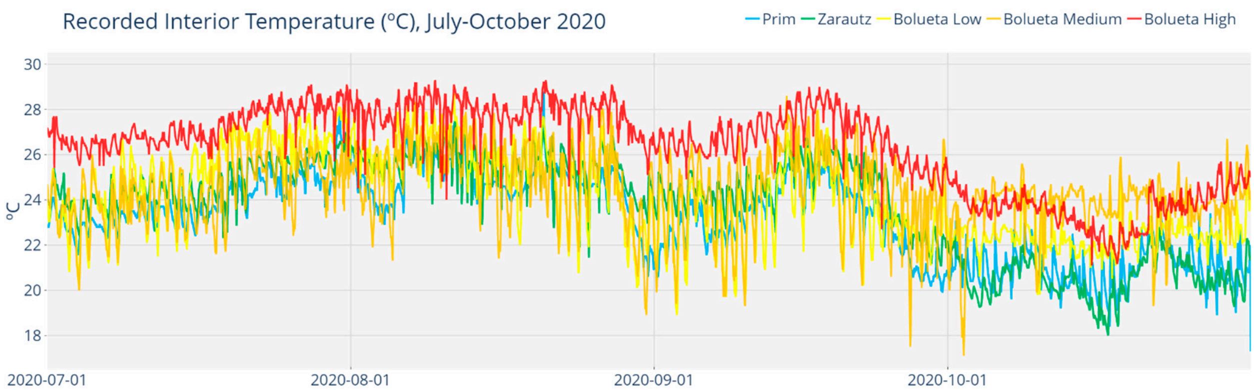


Figure 17. Recorded interior air temperature for all living rooms, 1 July to 31 October 2020. Source: authors.

By studying the temperature evolution per month, the different effects can be better described. Figure 18 shows the evolution of indoor temperatures during the month of July. The Bolueta High dwelling, as it does not use natural ventilation during the cool hours of the day, maintained very high temperatures constantly. The Prim and Zarautz dwellings showed day and night cycles in line with the outside climate, without great thermal stress. The Bolueta Low and Bolueta Medium dwellings carried out important ventilation actions during the night hours, which caused high maximum and minimum temperature differences in order to remain within the comfort zone. A similar effect was produced during the month of August.

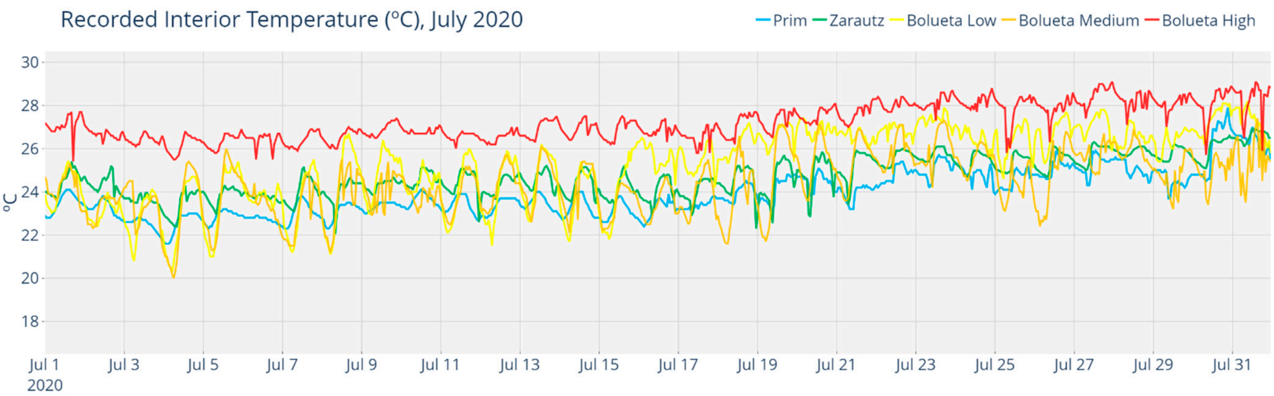


Figure 18. Recorded interior air temperature for all living rooms, July 2020. Source: authors.

We can see what happens in a month with cooler outside temperatures. In the month of October (Figure 19), it can be seen how the gaps between day and night temperatures in Bolueta Low and Bolueta Medium disappeared. Natural ventilation was no longer necessary to dissipate the heat and the cold outside generates discomfort when the windows are open. The dwellings reduced their interior temperature, although maintained high values, and it is the users who regulated the interior temperature more adequately. In the Bolueta High dwelling, we observed that these ventilation actions continued to be absent and that its temperature fluctuated between the average temperatures of the other Bolueta dwellings. For the Prim and Zarautz dwellings, it can be said that they entered a period of indoor comfort with a cool outdoor climate. The heating period had not started and at some moments minimum temperatures of 18 °C were observed; however, there were no major differences between the Prim and Zarautz dwellings, and even higher temperature values were observed due to higher occupancy, with four adults as opposed to two.

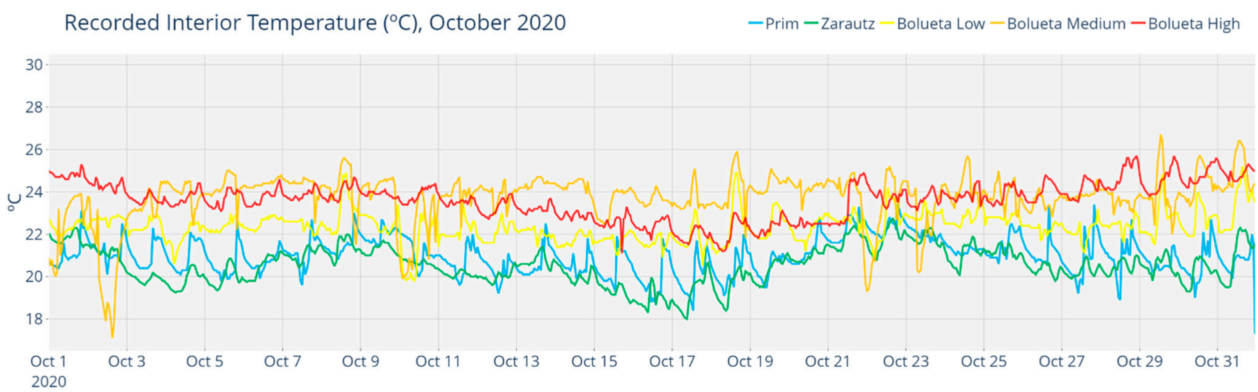


Figure 19. Recorded interior air temperature for all living rooms, October 2020. Source: authors.

If we look at the temperature and relative humidity pairs, the effects described above can be observed. Figure 20 shows the month of August in the five dwellings. The Prim and Zarautz apartments maintained temperatures between 23 and 27 °C, which we could say are in line with the outside climate. The Bolueta Low and Medium dwellings showed huge differences between minimum and maximum temperatures. Likewise, we can see that the maximum amount inhabitants managed to lower indoor temperatures by means of active ventilation was around 19 °C in Bolueta Low. In the case of Bolueta High, the little action of natural ventilation led to good indoor temperature records, between 26 °C and 29 °C.

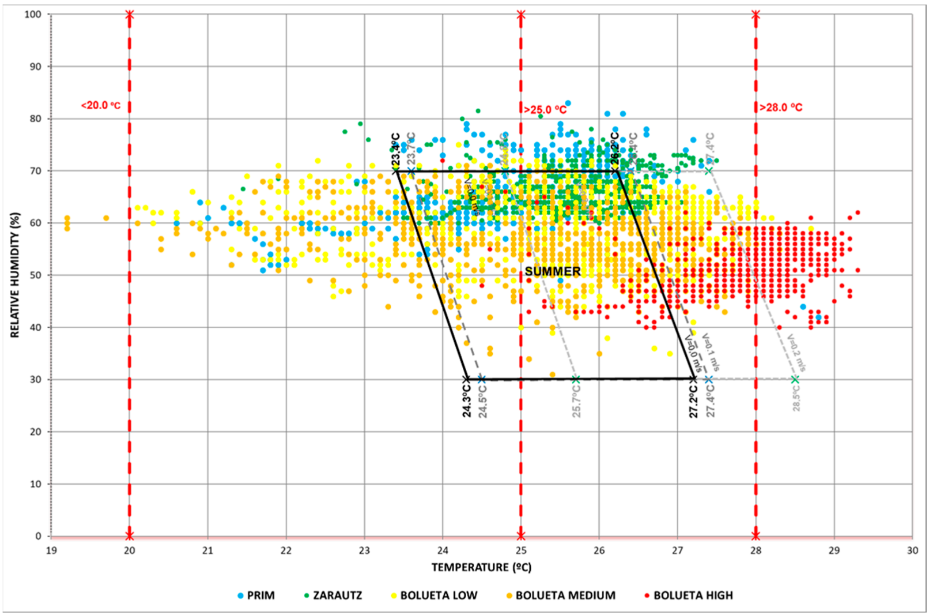


Figure 20. Summer comfort diagram for August 2020. Source: authors.

In September (Figure 21), with the drop in outdoor temperatures, it can be seen that the least insulated dwellings, Prim and Zarautz, saw their indoor temperatures drop, placing them within the comfort zone in accordance with the outdoor climate of the time in the city of San Sebastian. The Bolueta dwellings followed the same pattern. In the case of Bolueta Low and Bolueta Medium, we can say that the drop in outside temperatures helped to better dissipate the heat inside. However, the houses quickly returned to high temperatures as soon as the windows were closed. This is also due to the internal heat gain, which is difficult to dissipate with the mechanical ventilation system.

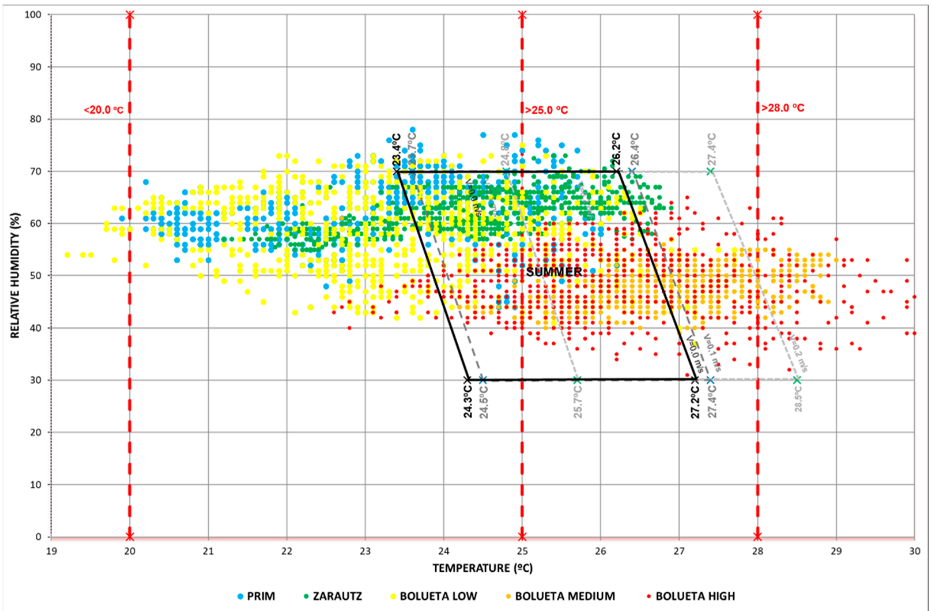


Figure 21. Summer comfort diagram for September 2020. Source: authors.

3.2. Night-Time Comfort

Night-time comfort is one of the most difficult aspects to achieve in highly insulated dwellings. The CIBSE Guide A recommends a maximum of 1% of annual hours > 26 °C in bedrooms, as stated in CIBSE TM:59 with the following criteria: "*To ensure comfort during sleeping hours the operating temperature in the bedroom from 10 p.m. to 7 a.m. should not exceed 26 °C for more than 1% of the annual hours (32 h)*".

Three bedrooms were monitored in two of the sites. As it will be seen below, temperatures were generally higher in the bedrooms than in the living room. In Table 11, the number of hours with temperatures above 26 °C is shown.

Table 11. Number of night-time hours (22:0008:00) where T > 26 °C, April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim	Living R.				11 [1]	21	0	0
	Bedroom 1				24 [1]	111	33	0
	Bedroom 2				13 [1]	51	16	0
Zarautz (Living Room)		0	0	0	2	49	26	0
Bolueta	Low	0	0	0	106	71	5	0
	Low-Bedr.				8 [2]	73	19 [2]	
	Medium	0	0	0	6	64	20	0
	High	0	61	120	264	279	268	18 [3]

[1] Incomplete month, monitoring starts 16 July. [2] Incomplete month, the monitoring period only covers 16 July to 21 September. [3] Incomplete month, monitoring ends 21 October.

It should be noted that the Prim and Zarautz dwellings did not include any complaints about night-time comfort in the surveys, and the excess hours may be due to certain periods in which the dwelling was not inhabited in August, for example, and in which proper ventilation was not carried out. In the Bolueta dwellings, night-time discomfort was a recurrent complaint, so it is common for dwellers to sleep with the windows open whenever they are not affected by outside noise.

The following graphs show a comparison between rooms in the day and at night-time. Both the living rooms and the master bedroom of the dwellings were monitored. Figure 22 shows a comparison for the month of August 2020 of the pairs of T and RH for the Prim and Bolueta Low dwellings. In the Prim dwelling, it can be seen that in general, the temperature of the bedroom was higher than that of the living room in both dwellings. This was due to the fact that the windows of the living room were open during the day; however, during the night they tended to remain closed. This was not the case in the Bolueta Low dwelling. The temperature in the living room was higher than in the bedroom, mainly due to the direct solar radiation that hits the dwellings. The inhabitants of Bolueta Low declared that they opened their bedroom windows every night around 5 or 6 a.m. in order to dissipate the heat and kept the door of their bedroom open all night.

Figure 23 shows the same comparison in September. Here, we can see how the drop in outside temperature and radiation means that the bedroom again exceeded the temperatures in the Bolueta Low dwelling. The logger stopped sending data from 16 September.

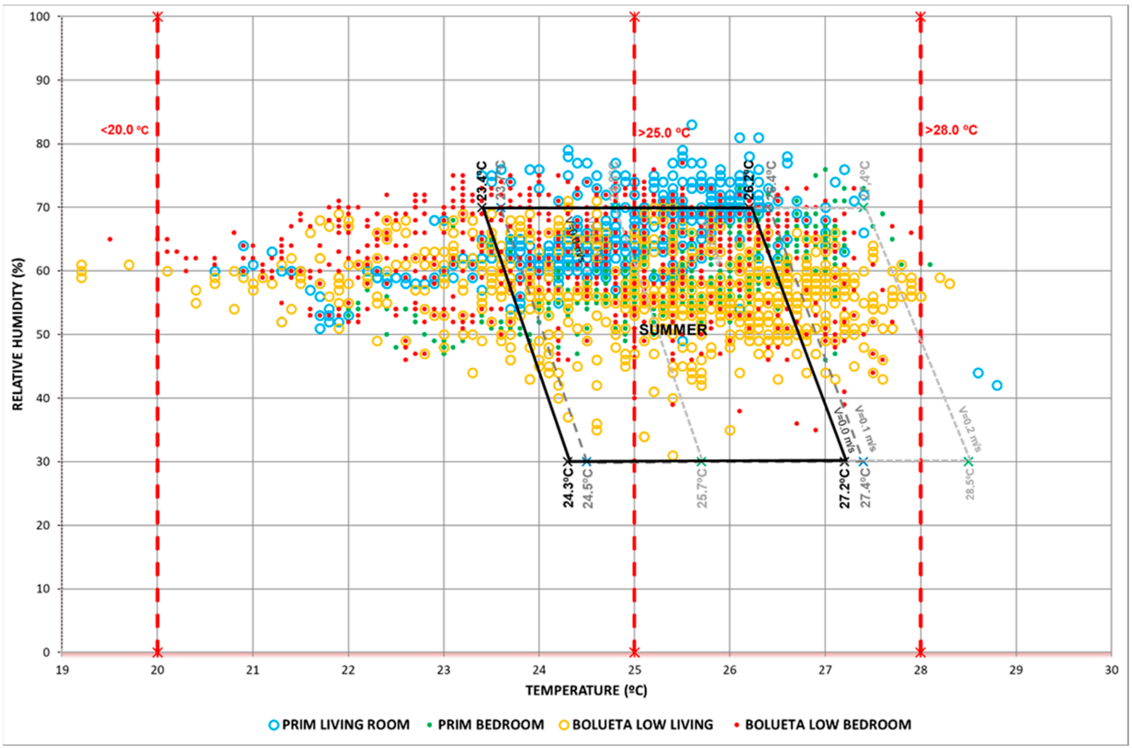


Figure 22. Summer comfort diagram comparison for both Prim and Bolueta Low case studies. August 2020. Source: authors.

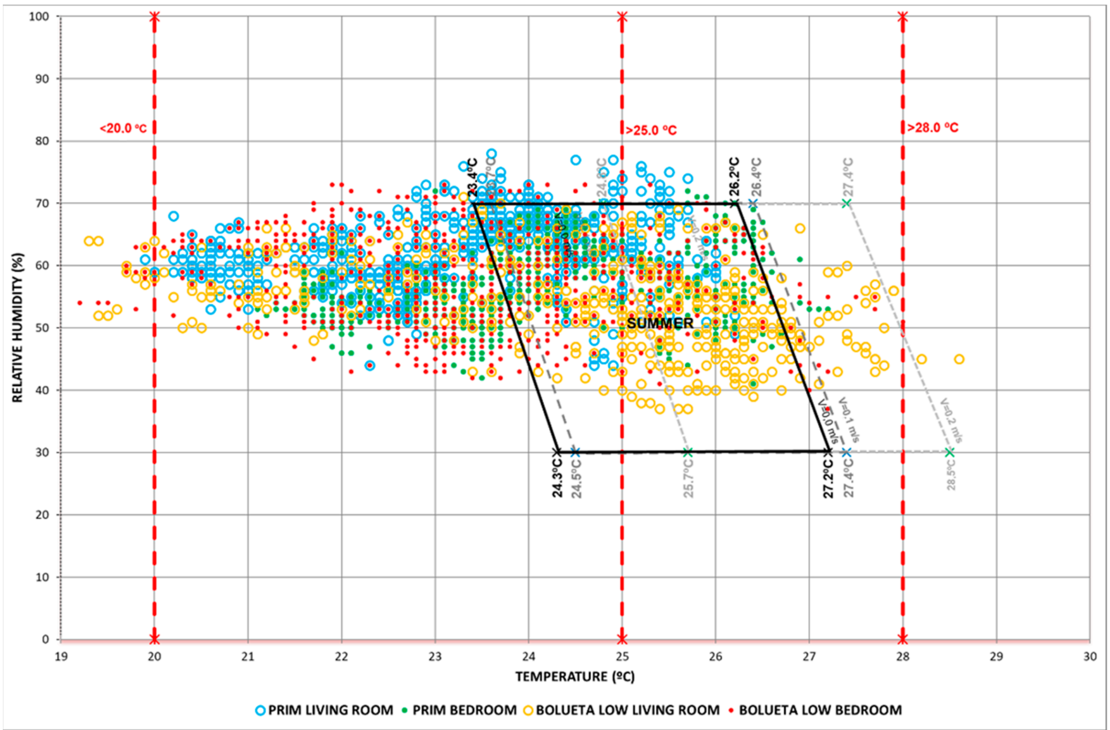


Figure 23. Summer comfort diagram comparison for both Prim and Bolueta Low case studies. September 2020. Source: authors.

3.3. CO_2 Concentration

For the apartments where an RTR-576 monitoring device was installed in the living rooms, data for CO_2 concentration is made available in Table 12. In the case of the Prim case study, the CO_2 monitoring devices were installed in bedrooms only.

Table 12. Mean CO_2 concentration (ppm), monthly, April–October 2020.

Case Study		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Prim—Bedroom 1 [1]					645 [2]	503	540	726
Prim—Bedroom 2 [1]					493 [2]	402	599	751
Zarautz		595	581	523	543	520	551	582
Bolueta	Low	566	552	509	552	578 [3]		
	Medium	573	559	511	470	473	481	581
	High	581	596	606	574	601	598	586 [4]

[1] Data from bedroom instead of living room. [2] Incomplete month, monitoring starts 16 July. [3] Incomplete month, the RTR-576 device installed in the living room was moved to the bedroom on 17 August. [4] Incomplete month, monitoring ends on 21 October.

4. Discussion

This section summarizes and discusses the results presented in the previous section and analyzes the compliance of the case studies with the standards and criteria introduced in Section 2.4.

In all the studied cases, average monthly temperatures were higher in the Bolueta units when compared to Prim and Zarautz (Table 6). The highest mean monthly temperature was recorded in the Bolueta High case study in the month of August (27.9 °C). It was also found that average monthly temperatures fell more rapidly when summer ended in the older, non nZEB houses (20–21 °C), whereas the Passivhaus-certified units sustained mean temperatures of 22–24 °C.

Bolueta Low, Medium and High showed a greater temperature range (Table 10), meaning there is a bigger amplitude in the temperature graph. The case of Bolueta Medium, where residents stressed the amount of manual ventilation they performed, is worthy of mention, as it is the flat that presented a bigger difference between maximum and minimum temperatures for the months of May, June, July, September and October.

Recorded relative humidity values (Table 7) were not anomalous typically, with monthly averages between 44 and 66%, and absolute minimums and maximums of 38% and 75%, respectively. These values are usually lower than the outdoor RH and are to be expected in areas near to the coast. Bolueta Low, Medium and High maintained lower relative humidity values when compared to Zarautz and Prim.

As presented in Table 5, the Passivhaus Institut overheating criteria limits the number of hours exceeding an operative temperature of 25 °C to 10% of the natural year; thus, 876 h. The Prim case study, due to its shorter monitoring period, is the only one that did not exceed said limit, with the sum of hours where $T_{op} > 25$ °C being 527 (6.02% of the year). The rest of the flats, such as Zarautz (1150 h, 13.13% of the year), surpassed the limit and would, therefore, be considered overheated under this standard. Bolueta Low, Medium and High, despite being certified under this standard, widely exceeded the limit and did not meet the performance that is to be expected from them with 1282 (14.63%), 1345 (15.34%) and 3344 (38.17%) hours above 25 °C, respectively.

In addition, Table 8 shows how the period of overheating extends further than the calendar summer and also longer than the CIBSE TM:52 defined summer (May–August), with a very considerable number of hours above 25 °C in September and May, and occasionally also in April and October.

CIBSE TM:52, section 1.4.2.4, limits the number of hours above 26 and 28 °C for bedrooms and living rooms, respectively, at 1% of occupied hours, which corresponds with an absolute limit of 32 h in bedrooms and 55 h in living rooms. CIBSE TM:59 also applies the same night-time comfort criterion. Prim, Zarautz, Bolueta Low and Bolueta Medium met the requirement for the daytime, but failed the criterion for night-time comfort. Bolueta High, on the other hand, failed both.

CIBSE TM:59 also establishes an adaptative limit, where the number of hours during which ΔT between interior and exterior is greater than or equal to 1 °C cannot be more than 3% of the occupied hours (May to September).

Table 13 summarizes the compliance of each case study with the standards presented in Table 5, found in Section 2.

Table 13. Summary of overheating criteria compliance.

Case Study	Prim [1]	Zarautz	Bolueta Low	Bolueta Medium	Bolueta High
Passivhaus Institut	6.02% *"Acceptable"* [2]	**13.13% *"Poor"***	**14.63% *"Poor"***	**15.34% *"Catastrophic"***	**38.17% *"Catastrophic"***
CIBSE TM:52 (Cat.II) [3]					
Criterion 1	Pass	Pass	Pass	Pass	Pass
Criterion 2	**Fail**	Pass	Pass	**Fail**	**Fail**
Criterion 3	Pass	Pass	Pass	Pass	Pass
CIBSE TM:59 (Cat.II) [3]	Predominantly Naturally Ventilated				
Criterion 1	Pass	Pass	Pass	Pass	Pass
Criterion 2	**Fail**	**Fail**	**Fail**	**Fail**	**Fail**
CIBSE TM:59 (Cat.II) [3]	Predominantly Mechanically Ventilated				
Criterion 1	Does Not Apply	Does Not Apply	**Fail**	**Fail**	**Fail**

[1] The monitored period is 16 June 2020 to 31 October 2020. [2] Less than 10% is deemed acceptable, although less than 5% is recommended by the PHI. [3] Category II corresponds to a normal level of expectation; Category I is reserved for buildings with a high probability of being occupied by vulnerable and fragile persons.

In the table we can see how the compliance ratios were more difficult to achieve in the more insulated dwellings. Note how the Passivhaus Institut criterion for summer is presumably only met by the oldest uninsulated dwelling.

All the case studies had good or acceptable CO_2 concentrations during the April to October period, showing in some cases mean monthly values similar to the baseline CO_2 concentration found in urban environments. The lowest average concentrations were found in the summer period, as dwellers acted on their apartments' ventilation to mitigate excess heat, obtaining better indoor air quality as a result. The expected difference between bedrooms and living rooms was confirmed in the monitoring campaign results.

There is, however, an interesting tendency that arose around the month of October, when inhabitants of houses ventilated only through natural means stopped opening the windows so often. Data for Prim Bedroom and Bedroom 2 showed a quick rise of CO_2 concentration up to 756 ppm in October, and it is reasonable to expect that it only rises during the colder months, probably exceeding the 900 ppm limit set in the national regulation CTE DB-HS 3.

5. Conclusions

First, this paper provided an up-to-date perspective on the evolution of energy efficiency regulations and current trends in the residential building sector in Spain, and investigated the benefits they have brought and the new challenges that arise as a result.

Then, this article showed that it is reasonable to compare the performance and resiliency against overheating of housing in different cities inside the coastal area of the Basque Country, provided local climate particularities are taken into account.

As a result, this comparative study made it possible to confirm that nZEB dwellings are more prone to suffering overheating than conventional or older housing and for longer periods of time, and has provided data to quantify and characterize the phenomenon, especially in the following aspects:

- The amplitude of the temperature readings is greater the higher the performance of the building envelope is, in terms of insulation and airtightness.
- The former could be both caused by the reduced thermal inertia of the building and by the actions dwellers take to try to mitigate overheating, such as constant ventilation. For this reason, buildings equipped with MHRV systems can be analyzed under criteria for naturally ventilated ones, for instance, by using CIBSE TM:59 criteria (a) and (b).
- Buildings that are less efficient in winter can also be better at dissipating heat in an overheating event, and thus, more resilient in this aspect.
- nZEBs are fine-tuned machines that are more sensible to microclimate variations, internal heat gains, occupation density and solar radiation, especially if they are not fitted with adequate sun protection and do not have the potential for intensive ventilation (e.g., no cross-ventilation is possible due to the layout).
- The advances and developments in the regulations that limit winter energy demands and consumption should be accompanied with greater study on the implications they have in summer energy demands and thermal comfort.
- Bedrooms tend to experiment higher temperatures than other rooms used during the daytime, and should be the subject of future studies considering the impact this has in sleep quality and overall health, especially for aging people, small children and vulnerable people.

Lastly, this paper also showed modern nZEBs and buildings as old as 120 years are likely to maintain similar indoor CO_2 concentrations during the summer, as both are primarily naturally ventilated during the hot period. However, nZEB apartments equipped with mechanical heat-exchange ventilation perform much better in this regard during the winter (October and onwards, in this climate). In other words, the air quality benefits of having an MVHR ventilation system may only be appreciated in the winter, as this equipment becomes redundant during the summer months.

6. Physical Quantities and Units

(CO_2)	ppm	CO_2 Concentration
C_{ep}	kWh/m^2 y	Primary Energy Consumption
g	dimensionless	Solar Factor
L_{den}	dB	Complete Day Noise Level
L_n	dB	Night-time Noise Level
n50	h^{-1}	Hourly Air Changes at a Differential Pressure of 50 Pa
RH	%	Relative Humidity
T	°C	Temperature
U	W/m^2 K	Thermal Transmittance

Author Contributions: Conceptualization, J.O. and I.R.-V.; data curation, J.O. and I.R.-V.; funding acquisition, R.J.H., X.O. and I.R.-V.; investigation, J.O. and I.R.-V.; methodology, J.O. and I.R.-V.; project administration, I.R.-V.; software, J.O.; supervision, R.J.H., X.O., A.M.-G. and I.R.-V.; validation, R.J.H., X.O., A.M.-G. and I.R.-V.; visualization, J.O.; writing—original draft, J.O. and I.R.-V.; writing—review and editing, J.O. All authors have read and agreed to the published version of the manuscript.

Funding: This study has been partially funded by the Department of Architecture of the University of The Basque Country (UPV-EHU). In addition, part of the work presented in this paper was funded by the research Project 3SqAir, Sustainable Smart Strategy for Air Quality Assurance in Classrooms (SOE4/P1/E1004), funded by the Interreg Sudoe.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Acknowledgments: This work is part of the "nZEB in Public Housing in the Basque Country-Comfort and Life Quality" research project, financed by the Territorial Planning and Housing Department of the Basque Government and also part of the Project 3SqAir, Sustainable Smart Strategy for Air Quality Assurance in Classrooms (SOE4/P1/E1004), funded by the Interreg Sudoe. This research work is part of the corresponding author's Thesis funded by the Call for Tender for a Researcher

Training at the University of the Basque Country UPV/EHU 2021 (PIF21/235). The authors would like to thank the residents of the Bolueta Tower I and of the apartments of Zarautz and Prim for their collaboration in the monitoring campaign. The authors would also like to thank the Municipal Housing Agency Viviendas Municipales de Bilbao, as well as Rubén Llanera from SAFER Instrument and M. Romeo Gurruchaga from the School of Architecture of San Sebastian.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon Dioxide
CTE	*Código Técnico de la Edificación* (English: Technical Building Code)
CTE DB-HE	*Código Técnico de la Edificación: Documento Básico Ahorro de Energía* (English: Technical Building Code—Energy Savings section)
CTE DB-HS	*Código Técnico de la Edificación: Documento Básico Salubridad* (English: Technical Building Code—Sanitary Conditions section)
DHW	Domestic Hot Water
EU	European Union
EVE	*Ente Vasco de la Energía* (English: Basque Energy Agency)
FTP	File Transfer Protocol
GHG	Greenhouse Gases
h	Hour
LBL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Environmental Design
MVHR	Mechanical Ventilation Heat Recovery
NBE CT-79	*Norma Básica de la Edificación: Condiciones Térmicas en los Edificios* (English: Basic Standards for Buildings: Thermal Conditions)
nZEB	Net Zero Energy Building
PH	Passivhaus
PHI	Passivhaus Institut
POE	Post-Occupancy Evaluation
RH	Relative Humidity
RITE	*Reglamento de Instalaciones Térmicas en los Edificios* (English: Regulation of Thermal Installations in Buildings)
T&D	T&D Corporation
TM	Technical Memorandum
TMYx	Typical Meteorological Year
UTM	Universal Transverse Mercator Coordinate System
VPO	*Vivienda de Protección Oficial* (English: Public Protected Housing)
YoC	Year of Construction

References

1. Brew, G. OPEC, International Oil, and the United States. In *Oxford Research Encyclopedia of American History*; Oxford University Press: Oxford, UK, 2019. [CrossRef]
2. Long-Term Low Greenhouse Gas Emission Development Strategy of the European Union and its Member States | UNFCCC, Council of the European Union. 2020. Available online: https://unfccc.int/documents/210328 (accessed on 16 November 2021).
3. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings, European Parliament. 2010. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0031 (accessed on 11 January 2019).

4. Commission Recommendation (EU) 2016/1318 of 29 July 2016 on Guidelines for the Promotion of Nearly Zero-Energy Buildings and Best Practices to Ensure that, by 2020, All New Buildings are Nearly Zero-Energy Buildings, European Commission. 2016. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016H1318 (accessed on 1 October 2020).
5. European Union 2020 Climate & Energy Package. Available online: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en (accessed on 9 December 2021).
6. European Union 2030 Climate & Energy Framework. Available online: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en#tab-0-0 (accessed on 16 November 2021).
7. Burke, R.V.; Gil, M.S.; González, D.J.; Rodríguez, J.S. *Guía de Aplicación DB HE 2019*; Ministerio de Transportes, Movilidad y AgendaUrbana: Madrid, Spain, 2020; Available online: https://www.codigotecnico.org/pdf/GuiasyOtros/Guia_aplicacion_DBHE2019.pdf (accessed on 16 November 2021).
8. Technical Standards for Homes | BREEAM—Sustainability Assessment Method. Available online: https://www.breeam.com/discover/technical-standards/homes/ (accessed on 16 November 2021).
9. LEED Rating System | U.S. Green Building Council. Available online: https://www.usgbc.org/leed (accessed on 27 December 2021).
10. Passivhaus Institut. Available online: https://passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm (accessed on 16 November 2021).
11. The MINERGIE Standard for Buildings. Available online: https://residence-immobilien.ch/sites/default/files/the_minergie_standard_for_buildings_en_0.pdf (accessed on 16 November 2021).
12. CASBEE Comprehensive Assessment System for Built Environmental Efficiency. Available online: https://www.ibec.or.jp/CASBEE/english/document/CASBEE_brochure_2016.pdf (accessed on 16 November 2021).
13. Fletcher, M.J.; Johnston, D.K.; Glew, D.W.; Parker, J.M. An empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. *Build. Environ.* **2017**, *121*, 106–118. [CrossRef]
14. Tabatabaei Sameni, S.M.; Gaterell, M.; Montazami, A.; Ahmed, A. Overheating investigation in UK social housing flats built to the Passivhaus standard. *Build. Environ.* **2015**, *92*, 222–235. [CrossRef]
15. Mitchell, R.; Natarajan, S. Overheating risk in Passivhaus dwellings. *Build. Serv. Eng. Res. Technol.* **2019**, *40*, 446–469. [CrossRef]
16. McLeod, R.S.; Hopfe, C.J.; Kwan, A. An investigation into future performance and overheating risks in Passivhaus dwellings. *Build. Environ.* **2013**, *70*, 189–209. [CrossRef]
17. da Graca, G.C.; Augusto, A.F.R.; Lerer, M.M. Solar powered net zero energy houses for southern Europe: Feasibility study. *Sol. Energy* **2012**, *86*, 634–646. [CrossRef]
18. Colclough, S.; Kinnane, O.; Hewitt, N.; Griffiths, P. Investigation of nZEB social housing built to the Passive House standard. *Energy Build.* **2018**, *179*, 344–359. [CrossRef]
19. Attia, S.; Eleftheriou, P.; Xeni, F.; Morlot, R.; Ménézo, C.; Kostopoulos, V.; Betsi, M.; Kalaitzoglou, I.; Pagliano, L.; Cellura, M.; et al. Overview and future challenges of nearly zero energy buildings (nZEB) design in Southern Europe. *Energy Build.* **2017**, *155*, 439–458. [CrossRef]
20. Larsen, T.S.; Jensen, R.L. Comparison of Measured and Calculated Values for the Indoor Environment in One of the First Danish Passive Houses. In Proceedings of the Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, Australia, 14–16 November 2011; pp. 1414–1421. [CrossRef]
21. Costanzo, V.; Fabbri, K.; Piraccini, S. Stressing the passive behavior of a Passivhaus: An evidence-based scenario analysis for a Mediterranean case study. *Build. Environ.* **2018**, *142*, 265–277. [CrossRef]
22. Hidalgo, J.M.; Psomas, T.; García-Gáfaro, C.; Millán, J.A. Overheating Assessment of a Passive House Case Study in Spain. In Proceedings of the 36th AIVC Conference "Effective Ventilation in High Performance Buildings", Madrid, Spain, 23–24 September 2015; pp. 645–655. Available online: https://www.aivc.org/resource/overheating-assessment-passive-house-case-study-spain (accessed on 16 November 2021).
23. Vidal, I.R.; Isasi, X.O.; de Arce, J.O. Overheating risk in social collective housing in the Basque Country and Navarre built under the Passivhaus standard Monitoring campaign and comfort analysis of a 171-dwelling building in Bilbao, Spain. In Proceedings of the 35th PLEA Conference on Passive and Low Energy Architecture (PLEA 2020), A Coruña, Spain, 1–3 September 2020; Gonçalves, J.C.S., Álvarez, J.R., Eds.; University of A Coruña: A Coruña, Spain, 2021; pp. 1281–1286. [CrossRef]
24. Vidal, I.R.; Otaegi, J.; Oregi, X. Thermal comfort in nZEB collective housing in Northern Spain. *Sustainability* **2020**, *12*, 9630. [CrossRef]
25. Bolueta in Bilbao, Spain, is Now the Tallest Passive House Building in the World—PRISM. Available online: https://prismpub.com/bolueta-in-bilbao-spain-is-now-the-tallest-passive-house-building-in-the-world/ (accessed on 31 October 2018).
26. Airtightness: One of the New Parameters in HE 2019—Colegio Oficial de Aparejadores y Arquitectos Técnicos de Bizkaia. Available online: http://www.coaatbi.org/tecnicos-edificacion-ante-cambio-climatico/hermeticidad-y-blower-door (accessed on 20 October 2020).
27. Pérez, M.R.; González, V.R. *Guía de Aplicación DB HE 2019—Ejemplos (I)*; Madrid, Spain, 2021; pp. 97–101. Available online: https://www.codigotecnico.org/pdf/GuiasyOtros/Guia_aplicacion_DBHE2019_Ejemplos_I.pdf (accessed on 16 November 2021).
28. Borrallo-Jiménez, M.; LopezDeAsiain, M.; Esquivias, P.M.; Delgado-Trujillo, D. Comparative study between the Passive House Standard in warm climates and Nearly Zero Energy Buildings under Spanish Technical Building Code in a dwelling design in Seville, Spain. *Energy Build.* **2022**, *254*, 111570. [CrossRef]

29. Laustsen, J. *Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings*; International Energy Agency: Paris, France, 2008. Available online: https://www.osti.gov/etdeweb/servlets/purl/971038 (accessed on 16 November 2021).
30. Economidou, M.; Todeschi, V.; Bertoldi, P.; D'Agostino, D.; Zangheri, P.; Castellazzi, L. Review of 50 years of EU energy efficiency policies for buildings. *Energy Build.* **2020**, *225*, 110322. [CrossRef]
31. UK National Energy Efficiency Action Plan. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/307993/uk_national_energy_efficiency_action_plan.pdf (accessed on 16 November 2021).
32. Arrêté du 10 avril 1974 relatif à l'isolation thermique et au réglage automatique des installations de chauffage dans les bâtiments d'habitation, République Française. 1974. Available online: https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000853955/ (accessed on 16 November 2021).
33. Guazzi, G.; Bellazzi, A.; Meroni, I.; Magrini, A. Refurbishment design through cost-optimal methodology: The case study of a social housing in the northern Italy. *Int. J. Heat Technol.* **2017**, *35*, S336–S344. [CrossRef]
34. Friege, J. Increasing homeowners' insulation activity in Germany: An empirically grounded agent-based model analysis. *Energy Build.* **2016**, *128*, 756–771. [CrossRef]
35. Decreto 1490/1975, de 12 de junio, por el que se establecen medidas a adoptar en las edificaciones con objeto de reducir el consumo de energía., Presidencia del Gobierno de España, Madrid. 1975. Available online: https://www.boe.es/buscar/doc.php?id=BOE-A-1975-14782 (accessed on 17 November 2021).
36. Graham, H. Spain's Transition to Democracy. *Hist. J.* **1990**, *33*, 1017–1023. [CrossRef]
37. Real Decreto 2429/1979, de 6 de julio, por el que se aprueba la norma básica de edificación NBE-CT-79, sobre condiciones térmicas en los edificios, Presidencia del Gobierno de España, Madrid. 1979. Available online: https://www.boe.es/boe/dias/1979/10/22/pdfs/A24524-24550.pdf (accessed on 17 November 2021).
38. Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación; Ministerio de Vivienda del Gobierno de España: Madrid, Spain. 2006. Available online: https://www.boe.es/boe/dias/2006/03/28/pdfs/A11816-11831.pdf (accessed on 17 November 2021).
39. Spain Building Code Implementation-Country Summary. Available online: https://tools.gbpn.org/sites/default/files/Spain_Country%20Summary_0.pdf (accessed on 17 November 2021).
40. Real Decreto 1027/2007, de 20 de julio, por el que se aprueba el Reglamento de Instalaciones Térmicas en los Edificios. 2007. Available online: https://www.boe.es/boe/dias/2007/08/29/pdfs/A35931-35984.pdf (accessed on 17 November 2021).
41. Reglamento de Instalaciones Térmicas en los Edificios (RITE). Versión consolidada 2013., (2013) 1–137. Available online: https://energia.gob.es/desarrollo/EficienciaEnergetica/RITE/Reglamento/RDecreto-1027-2007-Consolidado-9092013.pdf (accessed on 17 November 2021).
42. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, European Parliament and Council of Europe. 2002. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0091&from=EN (accessed on 17 November 2021).
43. Orden FOM/1635/2013, de 10 de septiembre, por la que se actualiza el Documento Básico DB-HE "Ahorro de Energía", del Código Técnico de la Edificación, aprobado por Real Decreto 314/2006, de 17 de marzo; Ministerio de Fomento del Gobierno de España: Madrid, Spain. 2013. Available online: https://www.boe.es/boe/dias/2013/09/12/pdfs/BOE-A-2013-9511.pdf (accessed on 17 November 2021).
44. Real Decreto 238/2013, de 5 de abril, por el que se modifican determinados artículos e instrucciones técnicas del Reglamento de Instalaciones Térmicas en los Edificios, aprobado por Real Decreto 1027/2007, de 20 de julio; Ministerio de Presidencia del Gobierno de España: Madrid, Spain. 2013. Available online: https://www.boe.es/boe/dias/2013/04/13/pdfs/BOE-A-2013-3905.pdf (accessed on 17 November 2021).
45. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, European Parliament and Council of Europe. 2010. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=en (accessed on 24 October 2019).
46. Martín, A.D. Implementation of the EPBD in Spain—epbd-ca.eu. Available online: https://epbd-ca.eu/ca-outcomes/outcomes-2015-2018/book-2018/countries/spain (accessed on 1 December 2016).
47. Passive House Database: Certified Buildings in Spain. Available online: https://passivehouse-database.org/index.php?lang=en#s_8a6fbeafbefc885da12b06afade2af2c (accessed on 17 November 2021).
48. Passivhaus Designers and other Members in Spain—Plataforma Edificación Passivhaus (PEP). Available online: https://www.plataforma-pep.org/directorio-socios/?community=&certification=&occupations=&tipology=&institutions=&company=&search= (accessed on 17 November 2021).
49. Moreno-Rangel, A. Passivhaus. *Encyclopedia* **2020**, *1*, 20–29. [CrossRef]
50. First Spanish Passivhaus in Moraleda de Zafayona (Granada). Available online: https://passivehouse-database.org/index.php#d_1690 (accessed on 17 November 2021).
51. Barnes, J. Passivhaus Trust UK, Passivhaus Capital Cost Research Project. Available online: https://www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/150128%20PH%20Capital%20Costs.pdf (accessed on 1 January 2015).
52. Hopfe, C.; McLeod, R. *The Passivhaus Designer's Manual: A Technical Guide to Low and Zero Energy Buildings*; Routledge: London, UK, 2015. [CrossRef]

53. Nasuvinsa se une al Consorcio Passivhaus—Consorcio Passivhaus. Available online: https://www.consorciopassivhaus.com/nasuvinsa-se-une-al-consorcio-passivhaus/ (accessed on 18 November 2021).
54. Nasuvinsa—Navarra de Suelo y Vivienda S.A., Gobierno de Navarra—Nafarroako Gobernua. Navarra Social Housing. The Commitment of the Government of Navarra for Social Rental and Sustainable and Energy Efficient Building. Available online: https://www.nasuvinsa.es/ficheros/INFORME%20NHN%20Ingl%C3%A9s%20ok.pdf (accessed on 18 November 2021).
55. El Gobierno foral promociona 600 viviendas del plan de alquiler "Navarra Social Housing" | Noticias de Navarra en Diario de Navarra. Available online: https://www.diariodenavarra.es/noticias/navarra/2021/10/29/el-gobierno-foral-promociona-600-viviendas-plan-alquiler-navarra-social-housing-505705-300.html (accessed on 18 November 2021).
56. Bolueta, Proyectos Emblemáticos Visesa. Available online: https://www.visesa.euskadi.eus/bolueta/ (accessed on 18 November 2021).
57. Moreno-Rangel, A.; Sharpe, T.; McGill, G.; Musau, F. Indoor Air Quality in Passivhaus Dwellings: A Literature Review. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4749. [CrossRef]
58. Causone, F.; Tatti, A.; Pietrobon, M.; Zanghirella, F.; Pagliano, L. Yearly operational performance of a nZEB in the Mediterranean climate. *Energy Build.* **2019**, *198*, 243–260. [CrossRef]
59. Chvatal, K.M.S.; Corvacho, H. The impact of increasing the building envelope insulation upon the risk of overheating in summer and an increased energy consumption. *J. Build. Perform. Simul.* **2009**, *2*, 267–282. [CrossRef]
60. Myers, D.; Gorse, C.; Johnston, D. Understanding Factors Influencing Overheating: The UK's First Large-Scale Domestic Passivhaus Retrofit. *Sustain. Ecol. Eng. Des.* **2020**, *volume 1*, 393–410. [CrossRef]
61. Ibrahim, A.; Pelsmakers, S.L. Low-energy housing retrofit in North England: Overheating risks and possible mitigation strategies. *Build. Serv. Eng. Res. Technol.* **2018**, *39*, 161–172. [CrossRef]
62. Figueroa-Lopez, A.; Arias, A.; Oregi, X.; Rodríguez, I. Evaluation of passive strategies, natural ventilation and shading systems, to reduce overheating risk in a passive house tower in the north of Spain during the warm season. *J. Build. Eng.* **2021**, *43*, 102607. [CrossRef]
63. Rodrigues, L.; Sougkakis, V.; Gillott, M. Investigating the potential of adding thermal mass to mitigate overheating in a super-insulated low-energy timber house. *Int. J. Low-Carbon Technol.* **2016**, *11*, 305–316. [CrossRef]
64. Mavrogianni, A.; Wilkinson, P.; Davies, M.; Biddulph, P.; Oikonomou, E. Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Build. Environ.* **2012**, *55*, 117–130. [CrossRef]
65. Porritt, S.; Cropper, P.; Shao, L.; Goodier, C. Ranking of interventions to reduce dwelling overheating during heat waves. *Energy Build.* **2012**, *55*, 16–27. [CrossRef]
66. Beizaee, A.; Lomas, K.; Firth, S. National survey of summertime temperatures and overheating risk in English homes. *Build. Environ.* **2013**, *65*, 1–17. [CrossRef]
67. Lomas, K.J.; Kane, T. Summertime temperatures and thermal comfort in UK homes. *Build. Res. Inf.* **2013**, *41*, 259–280. [CrossRef]
68. Mavrogianni, A.; Davies, M.; Taylor, J.; Chalabi, Z.; Biddulph, P.; Oikonomou, E.; Das, P.; Jones, B. The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. *Build. Environ.* **2014**, *78*, 183–198. [CrossRef]
69. Taylor, J.; Davies, M.; Mavrogianni, A.; Chalabi, Z.; Biddulph, P.; Oikonomou, E.; Das, P.; Jones, B. The relative importance of input weather data for indoor overheating risk assessment in dwellings. *Build. Environ.* **2014**, *76*, 81–91. [CrossRef]
70. van Hooff, T.; Blocken, B.; Hensen, J.; Timmermans, H. On the predicted effectiveness of climate adaptation measures for residential buildings. *Build. Environ.* **2014**, *82*, 300–316. [CrossRef]
71. Gupta, R.; Kapsali, M. Empirical assessment of indoor air quality and overheating in low-carbon social housing dwellings in England, UK. *Adv. Build. Energy Res.* **2016**, *10*, 1–23. [CrossRef]
72. Makantasi, A.-M.; Mavrogianni, A. Adaptation of London's social housing to climate change through retrofit: A holistic evaluation approach. *Adv. Build. Energy Res.* **2016**, *10*, 99–124. [CrossRef]
73. Mulville, M.; Stravoravdis, S. The impact of regulations on overheating risk in dwellings. *Build. Res. Inf.* **2016**, *44*, 520–534. [CrossRef]
74. Fosas, D.; Coley, D.A.; Natarajan, S.; Herrera, M.; de Pando, M.F.; Ramallo-Gonzalez, A. Mitigation versus adaptation: Does insulating dwellings increase overheating risk? *Build. Environ.* **2018**, *143*, 740–759. [CrossRef]
75. Los vecinos de Torre Bolueta reclaman una solución por el exceso de calor en sus pisos | El Correo, El Correo. Available online: https://www.elcorreo.com/bizkaia/vecinos-torre-bolueta-20201026204852-nt.html (accessed on 18 November 2021).
76. Ramos, A.M. El Ensanche de San Sebastián, Antonio Cortázar y las referencias influyentes. *Ciudad. Y Territ. Estud. Territ.* **1999**, *XXXI*, 293–305. Available online: https://recyt.fecyt.es/index.php/CyTET/article/view/85582/62447 (accessed on 2 May 2022).
77. Martín-Garín, A.; Millán-García, J.A.; Hidalgo-Betanzos, J.M.; Hernández-Minguillón, R.J.; Baïri, A. Airtightness Analysis of the Built Heritage–Field Measurements of Nineteenth Century Buildings through Blower Door Tests. *Energies* **2020**, *13*, 6727. [CrossRef]
78. Meiss, A.; Feijó-Muñoz, J.; Padilla-Marcos, M.A. Evaluación, diseño y propuestas de sistemas de ventilación en la rehabilitación de edificios residenciales españoles. Estudio de caso. *Inf. De La Construcción* **2016**, *68*, e148. [CrossRef]
79. Mapa de ruido de Donostia-San Sebastián 2017—Medio Ambiente—Ataria. Available online: https://www.donostia.eus/ataria/es/web/ingurumena/ruido/mapa-de-ruido (accessed on 19 December 2021).

80. Mapa Estratégico de Ruido 2017—Bilbao. Available online: https://www.bilbao.eus/cs/Satellite?cid=1279175993929&language=es&pagename=Bilbaonet%2FPage%2FBIO_contenidoFinal (accessed on 19 December 2021).
81. Lomas, K.J.; Porritt, S.M. Overheating in buildings: Lessons from research. *Build. Res. Inf.* **2017**, *45*, 1–18. [CrossRef]
82. Passive House Institute. *Criterios para los Estándares Casa Pasiva, EnerPHit y PHI Edificio de baja demanda energética*; Darmstad, Germany, 2016; Available online: https://passipedia.org/_media/picopen/9f_160815_phi_criterios_edificios_es.pdf (accessed on 18 June 2022).
83. Chartered Institution of Building Services Engineers. *TM59 Design Methodology for the Assessment of Overheating Risk in Homes*; Chartered Institution of Building Services Engineers: London, UK, 2017.
84. *ISO 7730:2005*; Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. International Organization for Standardization: Geneva, Switzerland, 2005.
85. EN 16798-1:2019; Energy Performance of Buildings—Ventilation for Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. 2019. Available online: https://standards.iteh.ai/catalog/standards/cen/b4f68755-2204-4796-854a-56643dfcfe89/en-16798-1-2019 (accessed on 2 May 2022).
86. Chartered Institution of Building Services Engineers. *TM52 The Limits of Thermal Comfort: Avoiding Overheating in European Buildings*; Chartered Institution of Building Services Engineers: London, UK, 2013.
87. Descargas DesignBuilder—Aurea Consulting—DesignBuilder España. Available online: https://ecoeficiente.es/descargas-designbuilder/#toggle-id-6 (accessed on 19 December 2021).
88. TMYx Weather Files for WMO Region 6—Europe. Available online: https://climate.onebuilding.org/WMO_Region_6_Europe/default.html (accessed on 19 December 2021).
89. *ISO-ISO 15927-4:2005*; Hygrothermal Performance of buildings—Calculation and Presentation of Climatic Data—Part 4: Hourly Data for Assessing the Annual Energy Use for Heating and Cooling. International Organization for Standardization: Geneva, Switzerland. Available online: https://www.iso.org/standard/41371.html (accessed on 19 December 2021).
90. Ucar, J.; Iglesias, G.C.; Gamboa, M.L. *Manual de diseño bioclimático: (referido a la Comunidad Autónoma del País Vasco)*; Ente Vasco de la Energía (EVE): Bilbao, Spain, 1990.
91. Gutierrez, L.; Mendizabal, M. Mapa Térmico de la ciudad de Donostia—San Sebastián. Available online: https://www.donostia.eus/ataria/documents/8023875/0/DSSmapatermico_entregable_vdef+%281%29.pdf/a905bd6b-6615-96e3-1c3c-09d66e906457 (accessed on 19 December 2021).