Overheating Assessment of a Passive House Case Study in Spain

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ABSTRACT

In response to the European Energy Performance Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU, buildings have increasingly become more insulated in order to reduce the heating losses to a minimum. However, this could also lead to the problem of indoor high temperatures during warm and transition seasons. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) warns about increases in temperature of more than 4 ºC by the end of the century. Taking into account the different thermal comfort indices, this research analyses the overheating risk in a single family house built in Spain according to the Passivhaus standard. For the purpose of this research, we selected the following models: the Fanger Predicted Mean Vote (PMV) model defined in the ISO 7730:2005, the adaptive model defined in the EN 15251:2007, the criteria for overheating prevention defined in CIBSE TM52 in 2013 and the PH limitation about warmer temperatures. Moreover, we have analysed the influence of dwelling occupancy and the periods of verification over the results of each methodology.

The studied building has a high level of thermal insulation and air-tight envelope, reducing heat losses until a heating demand of 14 kWh/m2 per year. It is equipped with a convective heating system and a mechanical ventilation system with heat recovery, without any cooling system apart from the bypass configuration of the heat recovery unit and the window openings. The monitoring lasted more than a year, from January of 2013 until April of 2014, and includes both indoor environment and outdoor weather parameters.

The different criteria result in different outputs: According to the ISO 7730 standard, the discomfort caused by warm temperatures represents the 9.8 % of the non-heated season, which reaches up to 13.6 % when taking into account only the day-time rooms; this result is obtained through the weighted average of the temperatures in the kitchen, the living room and the dining room. On the other hand, the adaptive model EN 15251 leads to an outcome of only the 0.2% in the whole house and 1.7% in the weighted average temperature of the day-time rooms. The TM52 criteria for avoiding overheating risk shows that the building is not overheated because it meets the three criteria. The house doesn't meet the Passivhaus requirement, because the period over 25ºC exceeds 11.8 %.

Finally, we have analysed some guidelines about overheating risk assessment and proposed some improvements, such as including transition months of fall and spring, considering full time occupancy instead of specific timetables or splitting the building into different zones to detect local discomfort conditions.

KEYWORDS

Overheating, Passive house, Thermal comfort assessment.

1 INTRODUCTION

As a result of years of research, building energy performance has deeply changed the horizon of construction techniques and traditional parameters for building design. In recent years, many EU countries have developed their building policy for net Zero Energy Building (nZEB) (BPIE, 2015) as Passive buildings and it is necessary to control potential overheating in future warming scenario (IPCC, 2015). In this task, the socio-economic crisis impact in the construction sector has changed recently in the EU-28; evolving from a reduction of 18.6 % between 2008 and 2010 and 9,6 % between 2010 and 2013, to an actual significant increase of 6.1 % in 2013 and 2014 (Eurostat, 2015).

A literature review of the climatic context showed an uncertain future: Despite the fact that the global warming impact is unknown and depends on future actions, the last publication of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) has already predicted a warming of +4 ºC in Europe by 2100 (IPCC, 2013). In such a case, the energy demand for building cooling will increase even in new buildings with a high level of insulation (McLeod, 2013). In 2010, the Zero Carbon Hub (ZCH) cautioned about overheating (OH), stating that "*Given the prospect of significant warming, well within the expected lifetime of homes, this risk will increase with potentially serious consequences"* (Zero Carbon Hub, 2010). Thus, in our case of intermediate regions with mild weather it could cause many unexpected TC problems because of the recently imposed high level of insulation and their lack of traditional natural cooling systems: windows.

Looking for an OH definition, CIBSE TM52 states: "it implies that building occupants feel uncomfortably hot and that this discomfort is caused by the indoor environment" (CIBSE TM52, 2013). A recent study (McLeod, 2013) shows many high insulated buildings where inhabitants report warm temperatures. Unfortunately, there is no specific regulation to prevent OH in the EU or in Spain, but there are several methodologies to set limits to warm indoor T based on the limits for warm Thermal Comfort (TC), such as the traditional Fanger ISO 7730, the adaptive EN 15251 or the more recent CIBSE TM52 for OH prevention. A recent review of current TC indices (Carlucci, 2012) concludes that it is necessary to set a new TC index for OH risk prevention.

Regarding the residential sector, Passivhaus (PH) is one of the most well-known design standards in Europe, with thousands of buildings developed since 1991. In the words of PH founder: "*A Passive House is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply air which is required for sufficient indoor air quality without using additional recirculated air*" (Feist, 2007). The PH standard sets a fixed high temperature limit of 25ºC, with less than 10% of the hours per year over this limit. There are many examples of OH prevention around Europe; some results point to user strategies such as ventilation and shading as the key to keep indoor comfort level during hot periods (Mlakar, 2011). They also show that particular attention should be paid to some common problems in the construction process, as these could severely impact the final performance of low energy buildings (Guerra-Santin, 2013). It should be noted that it is possible to address these problems by carrying out timely monitoring activities so as to ensure the performance of buildings' systems. Another study about a multifamily PH recently built in the United Kingdom indicates that 72% of monitored flats failed their design criteria (Sameni, 2015) and points to the user behavior as the most significant factor in increasing or decreasing the risk of OH.

Hence, this study will focus in the warm season, given that the main objective of this research is the assessment of the overheating risk. Besides, different types of rooms will be analysed in the study to verify if the methodologies guarantee the comfort conditions in rooms of different use and orientations.

2 CASE STUDY AND METHODOLOGY

2.1 Description of analysed Passive House

The data was acquired from a detached single family building with PH certification, built in 2012 in the province of Alava, in northern Spain. It was designed according to local town planning regulations, which required a traditional pitched tile roof, thereby increasing room height and heated air volume. The dwelling shape is rectangular and oriented to the south to maximise the solar collection in winter. In the centre of the south facade the main entrance leads to an open foyer that connects with the dining room and the family room; the rest of the house is accessed by a corridor (see Figure 1 below). The building structure of reinforced concrete consists of a foundation slab, pillars and two pitched roof slabs, which result in a considerable thermal mass. The main façade, detailed in Table 1, is made of clay blocks with both internal and external thermal insulation. The building presents a net floor area of 176 m^2 and a heated air volume of 500 m^3; the rooms have pitched or flat ceilings with heights ranging between 2.3 and 3.6 m. Details of the house can be found in (Hidalgo J.M., 2013).

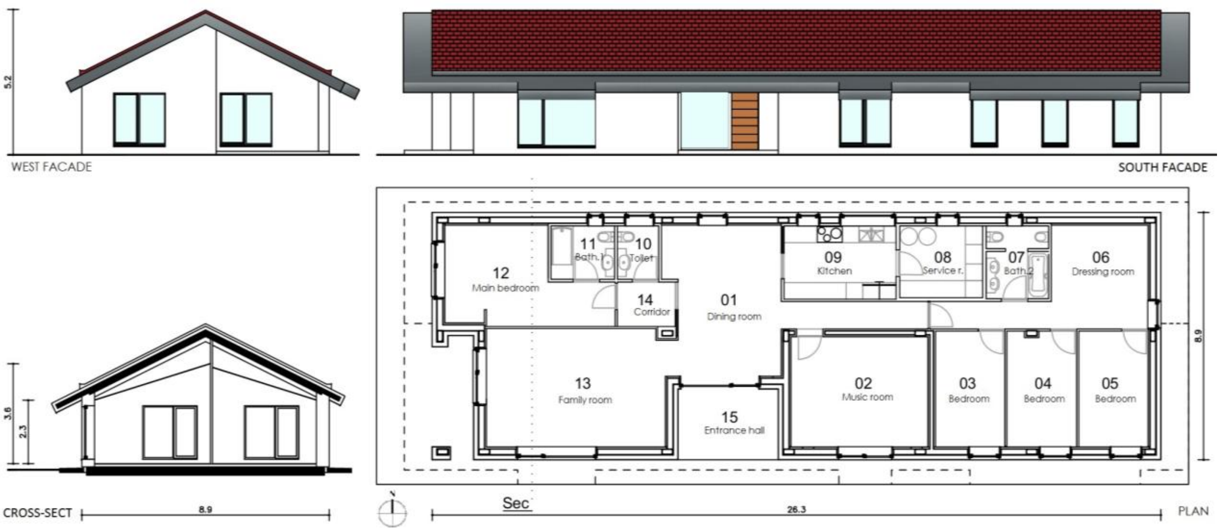

Figure 1: Passivhaus building plan, cross-section and main facades.

Table 1: Thermal envelope main elements and components

MAIN FACADE U = 0,143 W/m²K	**λ [W/(mK)]**	**width [mm]**	**GROUND SLAB U = 0,160 W/m²K**	**λ [W/(mK)]**	**width [mm]**
External plaster	0,870	6	EPS Neopor	0,036	160
EPS Neopor	0,032	160	Reinforced concrete slab	2,400	300
Mortar	1,300	15	EPS Neopor	0,036	50
Arliblock	0,460	200	Mortar levelling	1,300	50
Internal gypsum plaster	0,570	15	Floating wood floor	0,130	15
Rock wool	0,036	50			
Gypsum board	0,250	15			
ROOF U = 111 W/m²K	**λ [W/(mK)]**	**width [mm]**	**WINDOWS**	**U [W/(m²K)]**	**Solar gain [%]**
EPS Neopor	0,032	120	Frame, wood/alum. Mixed	1,00	-
Reinforced concrete slab	2,400	220	Glazing, 3pan, argon/Low E.	0,60	50
EPS Neopor	0,032	160	Window, average unit	0,9	-

The bioclimatic performance of the building was mainly conceived for the summer season, with pitched roof extensions that were designed as a means of protection against direct sun radiation in summer zenith; during winter it allows the absorption of the direct sun radiation. The entrance hall is conceived as a buffer-space and in winter it generates a greenhouse effect thanks to an outside glazing wall. The building heating demand was originally supplied by a biomass stove in the family room; however, it was replaced by two electric heaters located in the family room and in the dressing room. The indoor air quality (IAQ) is mainly provided by a mechanical ventilation system with exhaust air heat recovery (MVHR) with a measured seasonal performance (winter COP) of 86% during the 3 coldest months. During the summer season, the building is free-running and the cooling demand is provided by night-time ventilation due to HR bypass. The air exchange rate was set at 0.7 h^{-1} during all the monitoring period, except for some occasional family celebrations when the air flow was temporary increased. All the windows could be manually opened, and during the non-heated season the users used natural ventilation in combination with MVHR many warm days; it was verified by monitored temperature and relative humidity (RH). The hot water supply is provided by a combination of one solar thermal panel in the roof and a heat pump (HP).

2.2 Description of the Monitoring system

The acquisition system was installed to measure the building thermal response and indoor environment under normal occupancy conditions. The outdoor conditions were also measured in detail by a weather station placed in the plot of the house at a height of 3m. For a summary of all the parameters measured, types of sensors and uncertainties please refer to the Table 2 below. The indoor environment parameters were measured by air temperatures in all the rooms at a height of 2m, in conjunction with RH sensors in the main rooms. Additionally, some sensors were installed to measure the prospective vertical air temperature stratification in the rooms with high ceilings, such as the family room and the dressing room, where the air temperatures were measured at a height of 0.9m, 1.9m and 2.90m. Measurements were also made of some specific surface temperatures, such as walls, pillars, ceilings and floors of the main rooms. Furthermore, two additional sensors were placed to verify other TC parameters, like air velocity and globe temperature, over a period of several weeks throughout the different climatic seasons (spring, summer, fall and winter); thereby it was possible to verify the relation between air dry bulb temperature and operative temperature during different periods of the year.

The monitoring work was also aimed at gathering information for different analysis, which included the heating energy consumption, the window glazing and frame T, the performance of the entrance hall as sun collector, or the characterisation of the thermal envelope performance (with several months of heat flux measurements to calculate the facade transmittance according to ISO-9869-1). Table 2 below summarizes the main features.

Table 2: Main parameters measured by the data acquisition system.

Parameter	Sensor	Units	Num.	Uncertainty
T. air	RTD, PT100 (sheathed)	[ºC]	21	±0,2 ºC
T. surface	RTD, PT100 (encaps.)	[ºC]	57	±0,2 ºC
Relative Humidity	HIH-4000-001	[%]	6	±3,5 %
Heat flux	Ahlborn, Wärmefluss	[W/m^2]	3	±5 %
Electric power	JUMO, dTron 304	[W]	2	±4 %
Global H. Irradiance	Kipp&Zonnen, CMP11	[W/m^2]	1	±3 %
Meteorological Station	VAISALA, WXT520	[ºC], [mbar], [mm], [m/s], [%]	1	-
Data logger	AGILENT, 34980A	-	1	-

2.3 Overheating detection models and methodology

In a conversation with the inhabitants of the case study home, they shared their perceptions regarding the warm environment during some summer days and cold sensations in different parts of the building during winter. As a result, it was proposed to perform an exam of the Indoor Environment (IE), and specifically the Thermal Comfort (TC), in all the rooms of the home. Additionally, the rooms were classified following the criteria of orientation and use: Day-time (family room, dining room, and kitchen), Night-Time (bedrooms) and Services (service room, toilets, dressing room, corridors).

As we have seen before, the risk of OH has been assessed using many standards by calculating the IE warm limits according to an acceptable TC level. In order to perform this OH assessment, the current regulations and the most appropriate standards for the detection of OH risk were selected. First, the TC methodology provided in the current Spanish regulation for residential buildings was selected. The "Codigo Técnico de la Edificación" refers to ISO 7730 categories, also known as PMV-PPD model of Fanger (ISO 7730:2005). These limits are mandatory to every type of residential building, including the building of our case study, which doesn't have any cooling system. Second, the adaptive model EN15251 was selected, because this standard conforms specifically to buildings in free-running mode (without any cooling system during the warm season), which enables natural ventilation in every room (Olesen, 2012), the same features as in our studied building. This methodology applies specific categories to free-running buildings. This methodology calculates the limits depending on the outdoor running mean temperature (Trm). Third, with a view to measure the OH risk, it was instrumental to apply the most recent European methodology outlined in CIBSE TM52, despite the fact that it was designed bearing in mind Great Britain's weather conditions and British building regulations. Last, taking into account that the building was certified by Passivhaus Institute (PHI), it was interesting to ascertain if it meets the PH criteria to avoid OH, which consist on limiting the hours with average air temperatures over 25 ºC to less than 10 % of the time. All the methodologies used, as well as their temperature limits and periods of verification are summarized in Table 3 below. Given that most of these standards were developed originally for office buildings instead of residential use (CIBSE, 2013) (Carlucci, 2012), it is necessary to assess the impact of their assumptions about occupancy timetables and periods of verification, and to find out if they are valid for OH risk assessment in this residential building.

Table 3: Summary of TC standard limits according to indoor O.T.

TC Standard	Summer limits	Winter limits	Summer definition	Summer analyzed	Extended period
ISO 7730	24.5 ± 1.5	22.0 ± 2.0	(Non heating)	4Jun - 11Nov	15Apr - 30Nov
EN 15251	0.33 Trm +18.8 ±3	22.0 ± 2.0	(N.D.)	1Jul - 30Sep	15Apr - 30Nov
CIBSE TM:52	0.33 Trm +18.8 +3	(N.D.)	1 May - 30 Sep.	1May - 30Sep	-
PH overheating	25.0 (air T.)	25.0 (air T.)	(N.D.)	-	Full year

The period of verification is an important parameter for this assessment and, therefore, all available possibilities were examined. First, we studied the different definitions of the term "summer" according to astronomical, meteorological and temperature concepts (Alpert, 2004). According to the Meteonorm database and air temperatures parameter, the three warmest months in a typical meteorological year are: July, August and September. Second, the Fanger method ISO 7730 distinguishes between heated and non-heated periods. In our case, the heating system was switched off from the 4th of June till the 11th of November. In a similar way, the adaptive EN 15251 recommends the analysis of the whole year or a season, bearing in mind that the focus of our assessment is the summer season together with the transition months. Other more specific OH risk detection standards extend their periods of analysis to the whole year or at least they include part of spring and fall to prevent excessive solar gains during transition weeks after and before winter (Carlucci, 2012). This is precisely the approach advocated by the CIBSE TM52 methodology, with a longer period from May to September, a range probably selected to cover all the warm period in the UK. Given all these options, the study of the summer period has been complemented with an extended period that comprises the transitions of spring and fall: from the 15th of April until the 30th of November. The Figure 2**¡Error! No se encuentra el origen de la referencia.** below shows a summary of all these possible periods of verification.

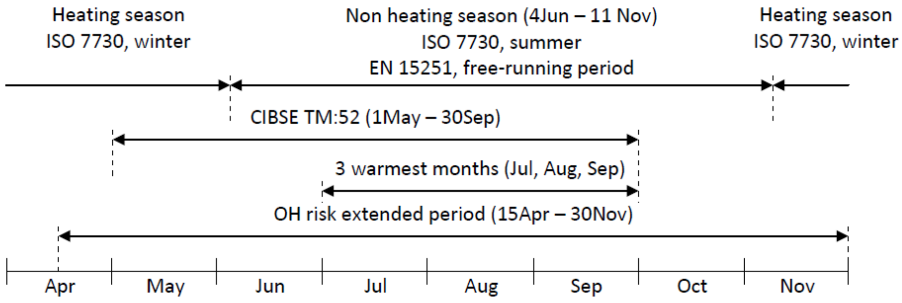

Figure 2: Periods of verification for summer TC conditions and OH detection

Additionally, the occupancy level indicates which hours are considered in the long-term analysis of the TC, as well as in the OH risk assessment. Most of the standards are only applicable whenever there are people at home. However, in our study we have proposed to measure also the unoccupied hours, mainly because future nZEB long time of response. This statement is based on the nZEB definition that assumes low heat losses through envelope and ventilation (BPIE, 2015). Hence, their IE will present fewer fluctuations than in traditional buildings. Taking into account all these issues, in our analysis they were assessed on two levels: full time occupancy and measured occupied hours. The timetable was an average of the real hourly occupancy detected by house monitored data during a representative number of weeks. For the purpose of calculating the average of the occupancy timetable, a week per month was selected during the 5-month period covering the spring and autumn seasons and, during the 3 months of summer, 3 weeks were selected. Figure 2 below shows the resulting timetable. For the purpose of the calculation, some days were excluded in order to account for the periods when the family was on holidays and out of their home for 1 day or more.

Day \ Hours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mon	5	5	5	5	5	5	5	5	0	0	0	1	4	4	3	1	0	3	3	3	5	5	5	5
Tue	5	5	5	5	5	5	5	5	0	0	1	1	4	5	4	1	0	1	1	2	4	5	5	5
Wed	5	5	5	5	5	5	5	5	1	0	0	1	4	4	4	1	0	1	3	4	4	5	5	5
Tue	5	5	5	5	5	5	5	5	2	0	0	1	5	5	5	3	1	2	5	4	3	4	4	4
Fri	5	5	5	5	5	5	5	5	0	1	1	0	4	4	4	2	1	2	1	1	2	3	3	4
Sat	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	2	3	3	3	4	3	3	3
Sun	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	3	4	4	5	5	5	5

Workweek
Occupancy check by hour along 5 weeks during workweeks within normal school calendar. Occupied if ≥ 3/5

Day \ Hours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mon	3	3	3	3	3	3	3	3	3	3	2	3	2	3	3	3	1	0	1	2	3	1	1	2
Tue	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0	0	0	0	1	1	2	2	3
Wed	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	2	2	1	1	1	1	2	3
Tue	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3	2	0	1	1	1	1	2	2	2
Fri	2	3	3	3	3	3	3	3	3	3	2	2	1	2	3	1	1	1	1	0	1	2	2	3
Sat	3	3	3	3	3	3	3	3	3	3	3	2	2	3	2	1	1	0	1	0	1	2	3	3
Sun	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3	3	2	1	1	0	0	2	2	3

Summer week
Occupancy check by hour along 3 weeks of summer during school holidays. Occupied if ≥ 2/5

Figure 3: Building occupancy timetables for summer and work week, averaged results.

3 RESULTS

All results are shown following the recommendations of the Strategic Research Centre for ZEB of AAU (Afshari, 2013) and disaggregated by occupancy, building zones and periods of evaluation. Despite the fact that the analysis is focused in high temperatures, considering the relevance of IE, **¡Error! No se encuentra el origen de la referencia.** and Table 5 also include low temperature discomfort ranges.

3.1 ISO 7730:2005

Focusing first on the global performance of the house and the occupied hours, 9.8 % of the summer period presents high temperatures, compared to 7.5 % during the extended period. At the same time, if we take into account the full time occupation, the rate increases up to 13.9 % and 9.6 % respectively, showing that some of the hottest hours are reached in the afternoon, when there is nobody at home. In relation to room combinations and orientations, during occupied hours Day-time reaches up to 13.6 % while Night-time remains similar at 7.8 %; however, when taking into account full time occupation, the gap increases till 18.4 % and 11.1 % respectively. This confirms that the areas with higher activity are more exposed to overheating risk. Considering the different orientations, we can say that the East side is fresher and the West side is hotter during all periods, while the hot temperatures in the North and South orientations are slightly below those in the West side. It is unexpected to find low temperatures around 20 % of the time; but this could be explained by both strict temperature limits of the standard (as we have seen in Table 3) and because the inhabitants preferred a low temperature set-point for heating.

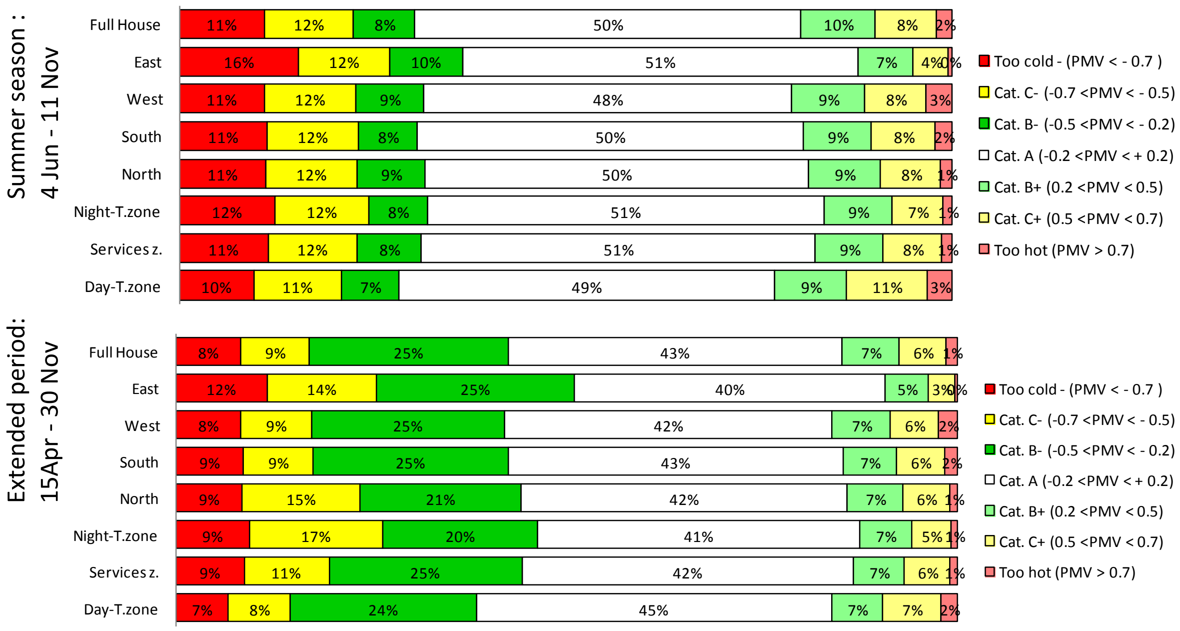

Figure 4: Thermal Comfort by building zones, considering real occupation, in summer and extended period.

Table 4: Discomfort percentages according to ISO 7730, occupied hours

Disconfort and period	Day-time z.	Service z.	Night-time z.	North	South	West	East	Whole House
High T. summer	13,6%	8,9%	7,8%	9,2%	10,4%	11,3%	5,0%	9,8%
Low T. summer	21,0%	23,0%	24,5%	23,0%	23,2%	22,9%	27,2%	22,6%
High T. extended	9,5%	6,8%	5,9%	7,0%	7,9%	8,6%	3,8%	7,5%
Low T. extended	14,7%	19,6%	26,5%	23,6%	17,6%	17,3%	25,7%	17,1%

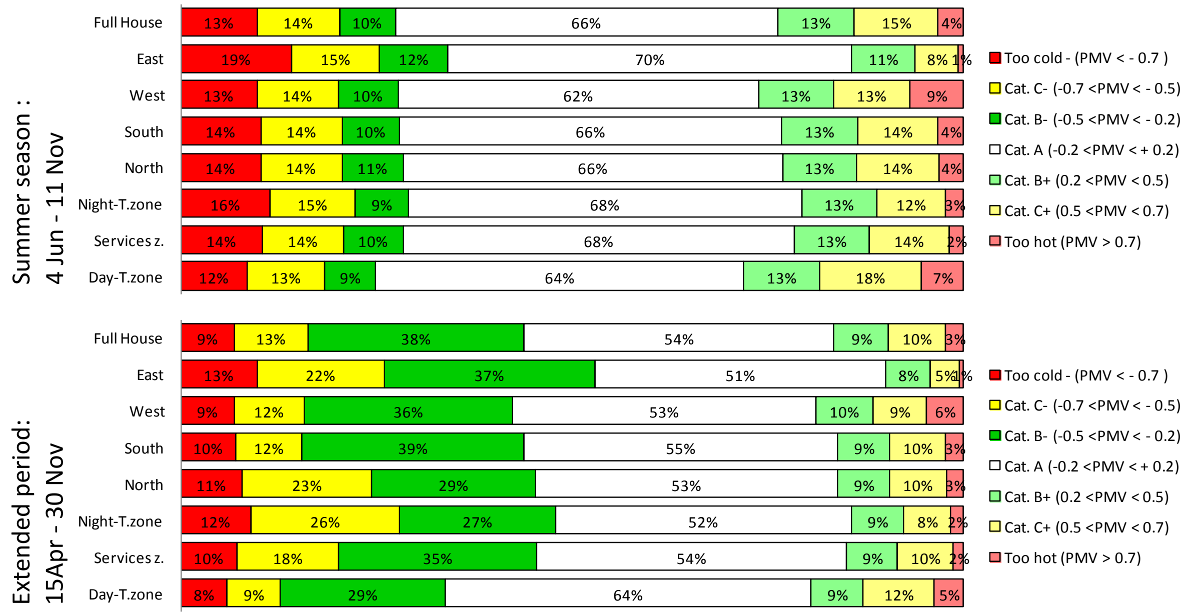

Figure 5: Thermal Comfort by building zones, considering full time occupancy, in summer and extended period.

3.2 EN 15251:2007

Figure 6 below shows the weighted indoor operative temperatures during the extended period, using different markers for non-heated season, spring and fall transitions. The main results according to EN 15251 indicate that discomfort rate by high temperatures stands at 0.2 % for both the summer and the extended period. There is low T discomfort during the transition weeks, which represents the 2.8 % of the extended period. Despite the aforementioned data, we can say that most of the hours fall within the adaptive limits of TC for IE, remaining within Categories I or II for 99.8 % of the summer period and 97.0 % of the extended period. Table 5 shows additional data about the different discomfort ranges taking into account criteria such as room use, orientation, occupied hours versus full time occupancy, and summer (non-heated, free-running period) or the extended period. Moreover, the table shows the relevance of selecting not only the "occupied hours", but also de "full time period", as the whole house discomfort caused by warm temperatures increases up to 0.6%.

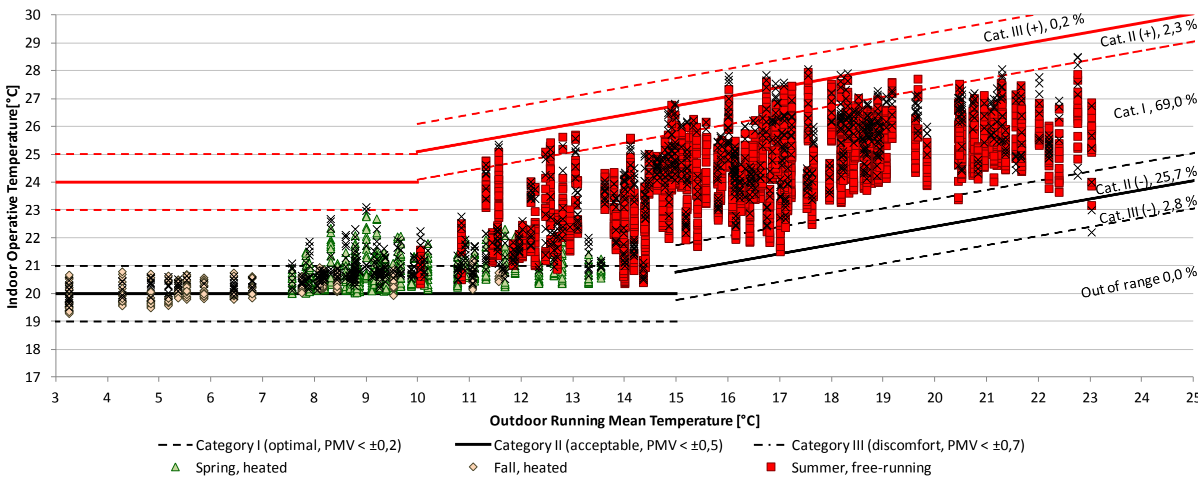

Figure 6: Thermal Comfort by EN 15251, during extended period.

Regarding the results in relation to the different room use and orientations, the Day-time rooms present higher temperatures, with 1.7 and 3.2 % for summer occupied hours and full time occupancy respectively. This is also the case in regards to orientations, with slightly higher temperatures in the West facade on comparison with the rest of the house. The high temperatures reach up to 0.7 % in occupied hours and up to 2,1 % in full time occupancy, showing this side is the most vulnerable part of the house for OH risk. Once again, the discomfort caused by low temperatures is located mainly in the bedrooms.

Table 5: Discomfort percentages according to EN 15251, by occupancy and period of verification.

Discomfort (high/low T), period and occupancy	**Day-time zone**	**Service zone**	**Night-time zone**	**North**	**South**	**West**	**East**	**Whole House**
High T. Summer, Occupied	1,7	0,0	0,0	0,1	0,3	0,7	0,0	0,2
Low T. Summer, Occupied	0,1	0,0	0,2	0,0	0,1	0,0	0,4	0,0
High T. Extended, Occupied	1,2	0,0	0,0	0,1	0,3	0,7	0,0	0,2
Low T. Extended, Occupied	0,1	7,0	14,3	11,9	1,7	2,4	10,0	2,8
High T. Sumer, Full time o.	3,2	0,2	0,2	0,3	0,7	2,1	0,0	0,6
High T. Extended, Full t. o.	2,2	0,2	0,2	0,3	0,7	2,1	0,0	0,6

3.3 CIBSE TM52

The first criterion of this methodology focuses on hours that exceed at least 1K over the EN15251 limits in a rounded value. In our building, despite having some Category III hours, their higher T only exceeded 0.4 K over the limit, so it can't be considered as exceedance values for this criterion and the building meets the criterion. Therefore, also meets the 2nd criterion, which required to check if any day presented a weighted temperature exceedance of 6 K and even the 3rd which limits the peak hour to an exceedance of 4K at any hour. Concluding that according to this methodology the three criteria are fulfilled, thus it could not be considered as OH.

3.4 Passivhaus requirements

Given the specifications of the PH standard, we have taken as reference a typical year of 8760 hours and we have checked all possible hours with Air T higher than 25 ºC in the weighted house temperature. Taking into account the Air T during the extended period, we find that the temperature surpassed 25ºC during 11.8 % of the time, which exceeds the 10 % threshold of the standard.

4 CONCLUSIONS

This case study shows that the Passive house built in the North of Spain cannot be considered as overheated, according to the results obtained in the latest regulation for OH prevention, CIBSE TM52 and EN15251. However, we have found that, with the 11.8 % of the time over 25 ºC, it does not meet the Passivhaus limitation. Similarly, it does not comply with the current Spanish regulation, because the frequent high and low temperature exceeds the ISO 7730 limits.

Every standard has proven to be useful or complementary in OH risk detection. The Spanish regulation methodology, based on ISO 7730:2005, can easily detect which zones of the building have higher risk of high temperatures, but it does not work so well during summer, mainly because in Europe or Spain these kind of residential buildings usually don't have any cooling system. On the other side, the EN 15251:2007 reflects more realistically the user perception, since looking into the days where they used additional natural ventilation they were close to the category III limit; so they felt warm and consequently used natural ventilation. Given that this was the first summer that users spent completely in the house, hopefully they will learn how to ventilate more efficiently in future summers. The CIBSE TM52 has proven a good step forward in OH risk detection, but it is still poorly defined in different building areas and limits rounding. Passivhaus OH prevention was conceived many years ago for cold central European climate, and after many years only a few variations have been introduced for warm climates. Despite the fact that the houses are high insulated and airtight, the IE limits have to be improved according to the outdoor environment influence, as happened with the EN 15251.

Many other problems have been detected in relation to local discomfort conditions depending on different activity areas or orientations. So, we recommend that the OH verification needs to be applied not only to a weighted house temperature but to two or more zones, depending on the size and shape of each case. It could be also necessary to make further research about local discomfort conditions for the most vulnerable rooms.

The obtained results for this highly insulated house show that the main shading elements were designed for summer sunpath and not for transitional months such as September or October, when there are still a lot of hours of radiation, with quite warm temperatures and few cloudy days. These factors in conjunction with the thermal mass of the building after summer could generate unexpected overheating in the end of summer. This issue must be considered in more detail in future building design.

We have seen how important it is to set properly the occupancy and the periods of verification according to each standard and knowing the differences between them. Further research is suggested in future case studies, considering the findings of the present study.

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