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PROCEEDINGS

In cooperation with:

Archetypes of public secondary schools in Mediterranean climate. Indoor air quality and comfort field studies

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ABSTRACT

Climate change is a growing global concern and building stock, in particular, is responsible for the emission of greenhouse gases, largely due to its poor energy efficiency. This problem is especially serious in educational buildings, where it is necessary to encourage energy efficient retrofitting under the parameters of nearly Zero Energy Building (nZEB), an objective which in Europe has been set for 2050. This is expected to produce economic, energy saving, hygrothermal comfort and health-safety benefits. In addition, the recent COVID-19 pandemic has shown the advisability of adding to the retrofit aims, ensuring good indoor air quality in spaces with high occupancy density and long stays, not only as a health and hygiene measure but also to minimize the socio-economic and labor repercussions associated with disruption to face-to-face teaching activity.

In recent years, field studies focused on environmental and energy conditions in educational centers have intensified. However, the selection of the study sample does not usually respond to statistical considerations. The first and principal objective of this work is to develop a database of public Secondary Education Centers (school ages between 14-18 years) in Andalusia, a large region covering the southern Spanish area of the Mediterranean zone, and to identify the archetypes that should be included in the study sample. The second main objective is to carry out a field study, in winter conditions, in a selection of the centers that conform to these archetypes, in order to ascertain the conditions of hygrothermal comfort and indoor air quality in the current pandemic situation.

In order to meet the first objective, a multi-parametric statistical analysis has been carried out which includes typological, constructive and operational characteristics as well as climate zoning. To achieve the second objective, several variables of environmental comfort and indoor air quality are monitored in the classrooms of the schools selected. Multifunction measurement equipment with sensors is used for indoor air temperature, indoor relative humidity, levels of CO_2 and particulate matter (PM).

The analysis of the database shows that approximately 41% of the public Secondary Education Centers in Andalusia were built before 1979, prior to the implementation of the first regulations on energy efficiency in Spain, while 53 % were built between 1979 and 2006, with regulations that are far from the nZEB requirements. The solution used in 95 % of the centers is natural ventilation, failing to comply with current regulations in Spain and compromising the air quality inside the classrooms when thermal comfort conditions cannot be achieved naturally. The statistical analysis according to different parameters of a study sample of 200 centers resulted in the selection of 39 archetypal centers, 6 of which were distributed to represent each climate zone in Andalusia and selected as the subjects of field studies on indoor air quality and thermal comfort. The results show predictably good indoor air quality as a result of the Covid continuous natural cross-ventilation protocol, but also good thermal comfort due to the unusually high winter temperatures.

KEYWORDS

IAQ, thermal comfort, Mediterranean climate, natural ventilation, school monitoring

1 INTRODUCTION

Global warming, the unprecedented environmental damage unequivocally caused by humans (IPCC, 2014), will have multi-scale repercussions in diverse fields, damaging ecosystem integrity (Wang et al., 2011) and human welfare. The building sector is currently responsible for 19% of greenhouse gas emissions (GHGs). Fortunately, increasing awareness of the scale of this global challenge among governments and international institutions has led to the establishment of goals such as the progressive reduction of emissions, aiming to almost completely reduce these by 2050, and minimizing the impact of human activities on the environment (European Green Deal 2019). The Energy Retrofit Program for Buildings, approved in 2021 in Spain, will invest 400 million euros in order to reduce energy consumption and CO_2 emissions in the building stock aiming to meet the parameters of nearly Zero Energy Buildings (nZEB).

In addition, another aim is to achieve a healthy indoor environmental quality in high occupation density and long stay spaces such as classrooms, thus reducing the socio-economic repercussions of the interruption of teaching activity, as recently experienced during the COVID-19 pandemic. The considerable benefits of the retrofitting of educational buildings include energy and economic savings, as well as student health, well-being and indoor comfort.

Due to the pandemic, natural cross, distributed and constant ventilation in buildings has been encouraged (Jiménez Palacios et al., 2021). However, natural ventilation is not a reliable system for achieving indoor air quality in winter conditions, even in mild climates such as the Mediterranean (Alonso et al., 2021) as, in addition to depending on external environmental pollution, it generally leads to a lack of thermal comfort (Fernández-Agüera et al., 2019) or a considerable increase in energy consumption (Stabile et al., 2019). Poor indoor air quality (IAQ) in schools inevitably leads to an increase in allergy and asthma in users (Madureira et al., 2015; Newman et al., 2020), as well as to serious repercussions contributing to the decrease of academic performance (Petersen et al., 2016). Therefore, the successive regulations that have been in place in the region since 1998 require mechanical ventilation to guarantee indoor air quality in classrooms.

The objectives of this work are two-fold: to identify the archetypes of public secondary schools in Andalusia and to carry out a field study in a selection of schools considered as archetypes to determine the main hygrothermal and air quality parameters in classrooms, in winter conditions and in a pandemic situation.

2 METHODS

In order to achieve these objectives, this work involves two main tasks:

- To compile a database of a representative sample of public secondary schools in order to identify archetypes following statistical analysis.
- To monitor the main hygrothermal and air quality parameters in classrooms of a selection of these archetypal centers in winter pandemic conditions.

2.1 Identification of the archetypes of public secondary schools in Andalusia

The selected area for the study is Andalusia, the southernmost region of Spain. The interest of this area lies in both its great size, approximately 8.75×10^6 ha, and the fact that it is the most populated region in Spain, around 8.5×10^6 people (18% of the total population in Spain). According to data from the Government of Andalusia there are 872 public secondary schools in Andalusia and this is an indicator of the size of the database developed. The clustering was established following different criteria: climate zoning; date of construction of the center and applicable regulations; typology of the centers; predominant orientation of the classrooms; constructive solutions of the envelope (facade, roof, openings and solar protection); and heating, ventilation and air conditioning (HVAC) systems.In addition to the large size of the database, the novelty is mainly related to the high number of criteria used for clustering, which makes the selection of archetypal centers for this and future research feasible.

Climate zoning (Figure 1) is the first criterion considered to establish the initial sample size. According to current regulations in Spain, climate zoning is defined by a letter and a number, based on winter climate severity, classified from lowest to highest using A-E, and summer climate severity, specified from lowest to highest using 1-4. According to the Köppen climate classification system (Rubel et al., 2011), there is a predominance of Csa typology (warm summer Mediterranean climate), although other climate variants can be found, especially in the eastern part of the region, with semi-arid dry climates, even desert (Bsk, BSh, BWh), Mediterranean climates with cool or temperate summers (Csb, Csc) and even continental climates (Dsb, Dsc) (*Agencia Estatal de Meteorología,* AEMET, 2011).

Figure 1. Map of climate zoning by municipalities in Andalusia.

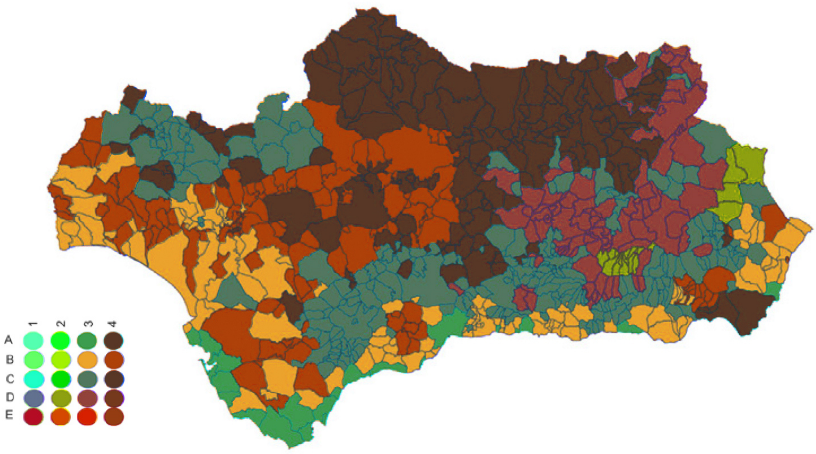


Table 1. Climate zoning of the full database of Andalusian centers with 872 schools.

FULL DATABASE (872 IES)						
			Summer climate severity			
			1	2	3	4
			0 %	*0 %*	*53 %*	*46 %*
Winter climate severity	A	*20 %*			149	24
	B	*47 %*			162	247
	C	*29 %*			120	134
	D	*4 %*		1	35	

Table 2. Climate zoning of the study sample with 200 schools.

SAMPLE DETAILED DATABASE (200 IES)				
			Summer climate severity	
			3	4
			52 %	*48 %*
Winter climate severity	A	*22 %*	44	
	B	*46,5 %*	32	61
	C	*31 %*	28	35

Table 1 shows the distribution of the total amount of centers in Andalusia according to the climate zone where they are located. As can be observed, the most representative zone is B4, with 247 centers (28%), followed by B3 (19%), A3 (17%), C4 (15%) and C3 (14%).

Once this first clustering criterion was established, prior to applying the remaining criteria, the study sample was limited to a selection of 200 centers reproducing the distribution by climate zones of the complete sample (Table 2), while the variation of the total set of centers, for a confidence level of approximately 90% and a 5% error margin of sampling, was unknown. The date of construction determines the minimum requirements and performance of the envelope and HVAC systems. Prior to 1979, there were no mandatory regulations on the thermal performance of the building envelope or on how to ventilate to control IAQ. After that date, the main regulations applicable to the construction of these educational centers were:

- NBE-CT, 1979. This was the first regulation to consider the thermal transmittance and hygrothermal behavior of the building envelope elements and of the building as a whole, as well as the air permeability of the windows and doors. The main parameter limited was the overall coefficient of thermal transmittance of the building (K_G).
- CTE, 2006. The K_G parameter was eliminated, and the limit transmittances of each of the envelope elements were substantially reduced compared to the previous standard.
- CTE, 2019. This is the most recent update of the previous regulation. It re-established K_G as the main parameter, although restricting it considerably to achieve the consideration of nZEB.

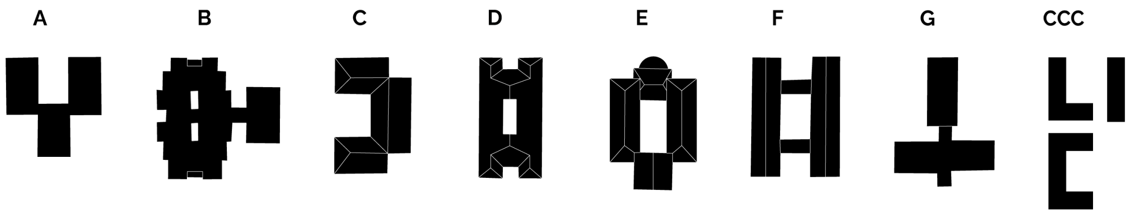
Given the date of construction of the educational centers and these main normative regulations, three regulation building periods have been considered: before 1979; from 1979 to 2006; and after 2006. Table 3 shows a balanced distribution between the first two periods, with 41% of the schools built before 1979, without energy efficiency requirements, and 53% between 1979-2006, with the NBE CT-79 requirements, which set few energy restrictions. The percentage of schools built according to CTE 2006 (7%) is not very representative and serves to illustrate the poor energy performance of school buildings in Andalusia in general.

Table 3. Distribution of school buildings according to construction dates and climate zones.

	REGULATION BUILDING PERIOD					
Climate zones	BEFORE 1979		1979-2006		AFTER 2006	
A3	*21*	**48 %**	*22*	**50 %**	*1*	2 %
B3	*4*	13 %	*23*	**72 %**	*5*	16 %
B4	*26*	43 %	*31*	**51 %**	*4*	7 %
C3	*11*	39 %	*16*	**57 %**	*1*	4 %
C4	*19*	**54 %**	*13*	37 %	*3*	9 %
	81	**(41 %)**	*105*	**(53 %)**	*14*	**(7 %)**

The next clustering criterion is the typological characterization of the schools (Figure 2). The most commonly used typology in the educational centers (79%) is CCC (Class-Corridor-Class) or CC (Class-Corridor) in different grouping variants: I, L or U.

Figure 2. Morphological models of public secondary schools in Andalusia.



Other criteria for clustering were the orientation of the classrooms, the proportion and geometry of the openings with respect to the facade and their solar protection, all classified according to climate zones. In A3, B4 and C3 the predominant orientation is southeast-northwest, in zone B3 it is northeast-southwest, while in C4 it is north-south. In all climate zones, the openings are medium-sized and, in general, occupy approximately 30% of the surface area of facades. The predominant type of solar protection in A3, C3 and C4 are blinds, while in B3 and B4 vertical blades are used. As a final criterion for clustering, the ventilation mode and heating systems were taken into account. 95% of the schools have only natural ventilation. In climate severity zone B, 46% have a heating system, while in zone C this percentage rises to 88%.

2.2 Monitoring

Hygrothermal and air quality parameters were monitored inside representative classrooms of the archetypal schools selected. Temperature, Relative Humidity, CO_2, $PM_{2.5}$ and PM_{10} measurements were taken using properly calibrated Sensonet Multisensor SW20 datalogger (Table 4).
Subsequently, IAQ and hygrothermal comfort analysis was performed by comparing these measurements with the normative or recommended limit values of the different parameters (Table 4). Outdoor environmental conditions data were obtained from the AEMET. Sensors were placed in the central area of one of the interior walls of each classroom at a height of 1.5-1.8 m (Figure 3) in order to avoid data distortions due to air flows and exposure to direct solar radiation. The individual schools were monitored for a two-week period, between the months of February and March. The results evaluate the environmental quality variables during the period of occupation, which is 7 hours a day in all the centers. The COVID protocol mentioned above, which was in place during the monitoring period, recommends natural cross-ventilation, being a highly relevant climatization factor.

Table 4. Monitoring device characteristics and reference and regulatory values.

Analysis field	Parameter	Units	Limit range	Accuracy	Limit or Reference Values			Regulations or recommendation
IAQ analysis	CO_2 concentration	ppm	0 to 5000	±10	900 ppm[1]			Cat II UNE-EN 16798
					1000 ppm			Pettenkofer number
	$PM_{2.5}$	µg/m³	0 to 1000	±15 < 100 ±15 % > 100	25 µg/m³			(WHO, 2021)
	PM_{10}	µg/m³	0 to 1000	±15 < 100 ±15 % > 100	50 µg/m³			
Hygro-thermal analysis	Air temperature (T)	ºC	-20 to +65	±0.5	24.8-19.8 ºC[2]	26.7-20.8 ºC	A3	Thermal comfort. Adaptive method: **Left:** (ANSI/ASHRAE Standard 55, 2010) **Right:** (UNE-EN 16798-1, 2020)
	Relative humidity (RH)	%	0 to 100	±3	25.8-20.8 ºC	27.9-21.9 ºC	B4	
	Outdoor Air temperature	ºC	-40 to 65	± 0,3	25.9-20.9 ºC	27.9-21.9 ºC	B3	
	Outdoor Relative humidity	%	0 to 100	± 3	24.4-19.4 ºC	26.7-21.0 ºC	C4	

[1] Assuming an outdoor CO_2 value of 400 ppm.
[2] Comfort bands (according to the outdoor temperature ranges of each climate zone).

Figure 3. Typical distribution of analyzed classrooms. Placement of sensors.

3 RESULTS AND DISCUSSION

3.1 Resulting archetypes, case studies

Once the 200 schools selected from the total amount were clustered, a multi-parametric graph was drawn up (
Figure 4) with the list of criteria described above. On this graph, the representative values for each criterion are marked with a horizontal bar in gray scale. A list of archetypes (between 7-9) is thus obtained for each of the 5 climate zones and their characteristics are described (Table 5). From this list, we chose to monitor 12 classrooms of these archetypal centers (
Table 6), reproducing the distribution shown in Table 2 as closely as possible: two centers in zone A3, two in zone B4, one in zone B3 and one in zone C4.

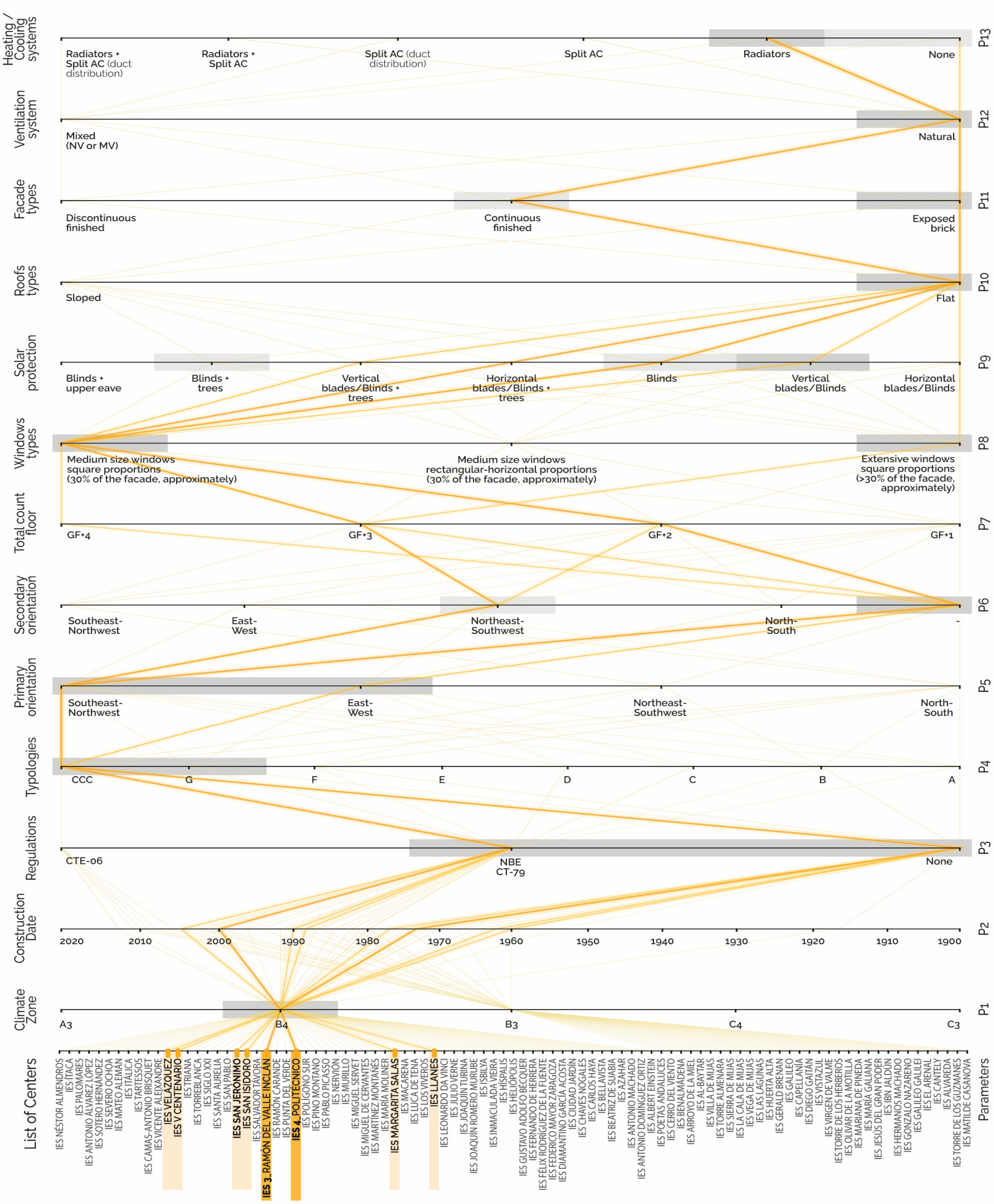
Table 5. Archetype's definition. All archetypes follow the CCC (Class-Corridor-Class) typology and have only natural ventilation systems.

Archetypes	**Climate Zone**	**Regulation building period**	**Classroom orientation**	**Classroom windows**	**Solar protection**	**Heating / Cooling systems**
9 centers	A3	(48%) before 1979 (50%) 1979-2006	(32%) Southeast-Northwest (30%) East-West	Medium sized (30% of facade), square windows	Blinds	None
7 centers	B3	(72%) 1979-2007	(34%) Northeast-Southwest (31%) East-West	Medium sized (30% of facade), square windows	Vertical blades	Radiators
8 centers	B4	(43%) before 1979 (51%) 1979-2008	(38%) Southeast-Northwest (26%) East-West	Large sized (50% of facade), rectangular windows Medium sized (30% of facade), square windows	Vertical blades or Blinds	Radiators
8 centers	C3	(39%) before 1979 (57%) 1979-2009	(57%) Southeast-Northwest	Medium sized (30% of facade), square or rectangular windows	Blinds (plus trees)	Radiators
7 centers	C4	(54%) before 1979	(31%) North-South (26%) Southeast-Northwest	Medium sized (30% of facade), square windows	Blinds	Radiators

Table 6. Summary of case study characteristics. All case studies follow the CCC (Class-Corridor-Class) typology and have only natural ventilation systems.

School ID	**Climate Zone (Location)**	**Regulation building period**	**Classroom orientation (Dimensions)**	**Classroom windows** **Solar protection**	**Heating / Cooling systems**	**Occupation profile**
IES 1	A3 (Malaga)	NBE CT-79 (1979-2006)	Southeast-Northwest (6.1 x 9 m, h=3 m Area = 54.9 m^2)	2 four-leaf sliding windows, *max. aperture 2x 2.25 m^2* Solar protection: Vertical blades	Radiators	30 students, *5.5 m^3/pers.* *(16 years old)*
IES 2	A3 (Malaga)	None (Before 1979)	Southeast-Northwest (6.2 x 9.2 m, h=3 m Area = 57 m^2)	2 four-leaf sliding windows, *max. aperture 2x 2.35 m^2* Solar protection: Blinds	None	25 students, *6.8 m^3/pers.* *(13 years old)*
IES 3	B4 (Sevilla)	NBE CT-79 (1979-2006)	Southeast-Northwest (5.8 x 7.9 m, h=2.75 m Area = 45.8 m^2)	5 two-leaf swing windows, *max. aperture 5x 0.65 m^2* Solar protection: Horizontal blades	Radiators + Fans	25 students, *5 m^3/pers.* *(16 years old)*
IES 4	B4 (Sevilla)	None (Before 1979)	Southeast-Northwest (6.3 x 9.4 m, h=3.15 m Area = 59 m^2)	3 three-leaf sliding windows *max. aperture 3x 0.95 m^2* Solar protection: Blinds	Radiators + Fancoils	28 students, *6.6 m^3/pers.* *(14 years old)*
IES 5	B3 (Dos Hermanas)	NBE CT-79 (1979-2006)	East-West (5.9 x 8 m, h=3 m Area = 47.2 m^2)	3 two-leaf sliding windows *max. aperture 3x 0.65 m^2* Solar protection: Vertical blades	Radiators + Split AC	28 students, *5.1 m^3/pers.* *(15 years old)*
IES 6	C4 (Córdoba)	None (Before 1979)	East-West (6 x 8.7 m, h=3 m Area = 52.2 m^2)	2 four-leaf sliding windows, *max. aperture 2x 1.9 m^2* Solar protection: Blinds	Radiators + Fans	30 students, *5.2 m^3/pers.* *(18 years old)*

Figure 4. Parallel coordinate multi-parametric graph for the selection of representative secondary schools in climate zone B4.



* The educational centers selected correspond to the archetype selection in zone B4, as shown in Table 5.

3.2 IAQ and Thermal Comfort in Archetypes

Table 7 presents a summary of the results of the IAQ parameters obtained during the 7 hours of occupancy (school day) in two classrooms with opposite orientations in each of the 6 archetypal centers. The regulatory or recommended limit values for the parameters are shown in Table 4. Suitable CO_2 values were observed in all the case studies and are attributed to the application of the COVID protocol, which required continuous natural ventilation in the classrooms. The average percentage of hours of the school day in which 1000 ppm is exceeded is very low. The centers located in climate zone B4 display the highest maximum values: between 7.9 and 22.4 %. All classrooms except one (SE of IES 3) are in category Cat I, which is the best level of IAQ as defined in UNE-EN 16798. Good results are also obtained for particulate matter, with $PM_{2.5}$ and PM_{10} values during the school day below the reference values, this could be due to the reduction in levels of particulate matter pollution in recent years, as indicated by the National Air Quality Index of the Spanish Ministry of Ecological Transition and the Demographic Challenge. Understandably the worst PM values are found in Malaga (A3) which, according to the latest source, has higher ambient concentrations of these particles. However, the accuracy of measurements makes it difficult to make statements with a high degree of certainty.

Table 7. Summary of IAQ analysis results.

School ID	Climate Zone	Class orientation	**CO_2 (ppm)**				**$PM_{2.5}$ (µg/m³)**		**PM_{10} (µg/m³)**	
			mean max. mean min. average	IAQ classification (based on UNE-EN 16798)	average | max daily % of hours over Pettenkofer number		mean max. mean min. average	average daily % of hours over 25 µg/m³	mean max. mean min. average	average daily % of hours over 50 µg/m³
IES 1	A3	SE	876.8 476.1 625.3	Cat I	0.8 %	7.8 %	28.0 14.8 20.6	**13.9 %**	33.5 14.7 23.4	5.2 %
		NW	805.6 454.7 602.0	Cat I	0.2 %	2.3 %	24.8 12.2 17.6	**10.0 %**	31.8 13.3 20.9	5.0 %
IES 2	A3	SE	750.2 461.8 582.3	Cat I	0.0 %	0.0 %	**32.3** 14.6 19.4	**9.1 %**	35.3 15.7 21.9	1.1 %
		NW	985.4 468.8 637.0	Cat I	3.4 %	**12.5 %**	**34.2** 15.1 20.5	**15.7 %**	**46.7** 16.7 23.3	2.1 %
IES 3	B4	SE	**1,147.2** 488.4 788.8	**Cat II**	**11.3 %**	**22.4 %**	15.0 4.1 8.6	0.0 %	16.1 4.3 9.0	0.0 %
		NW	980.6 461.2 695.6	Cat I	1.1 %	7.9 %	14.6 3.2 7.7	0.1 %	15.8 3.4 8.0	0.0 %
IES 4	B4	SE	**1,142.8** 451.2 654.4	Cat I	**6.9 %**	**16.8 %**	24.2 13.0 16.6	2.4 %	28.7 14.5 17.9	0.0 %
		NW	998.8 452.7 693.7	Cat I	2.1 %	**12.3 %**	24.0 15.3 18.8	2.4 %	27.5 16.3 20.4	0.0 %
IES 5	B3	E	**1,126.8** 400.0 568.3	Cat I	3.9 %	10.1 %	26.0 15.4 19.3	**12.5 %**	29.0 16.4 21.1	0.0 %
		W	952.3 400.0 560.4	Cat I	1.4 %	10.1 %	24.3 13.7 17.2	1.0 %	26.4 15.1 18.7	0.0 %
IES 6	C4	E	963.0 466.5 600.6	Cat I	3.4 %	6.7 %	6.0 0.0 1.7	0.0 %	6.0 0.0 1.7	0.0 %
		W	789.0 409.0 528.2	Cat I	0.0 %	0.0 %	16.0 9.0 13.4	0.0 %	17.0 9.0 14.6	0.0 %

The most relevant values are shown in bold type.
Class orientation: Southeast (SE), Northwest (NW), East (E) and West (W)

Table 8 shows a summary of the thermal comfort evaluation data for each of the centers analyzed over a one-week period (35 school hours). The outdoor temperature ranges vary slightly in each climate zone, with margins of 7.7 to 4 ºC between maximum and minimum, respectively. The comfort bands therefore vary according to the location of each center and the method used (Table 4). The indoor thermal variation between the different climate zones is 5.8 to 3.8 between maximum and minimum, respectively. Good results are obtained, with the exception of the classrooms in zone A3, with weekly discomfort percentages between 70 and 86 %. These good overall values are due to the unusually high winter temperatures which occurred during the monitoring campaign (Table 8). However, it can be seen that in the centers with higher percentages of hours in discomfort, this is due to temperatures below the lower limit of the comfort band. The comfort model proposed by ASHRAE is less restrictive, since the comfort band, although narrower, is obtained from monthly average temperatures and not daily as in the case of UNE 16798.

Table 8. Summary of thermal comfort analysis data.

School ID	Climate Zone	Class orientation	**Outdoor Temperature range** (ºC)			**Indoor Temperature range** (ºC)			**ASHRAE 55:2017** CAT I (PPD 10%)			**UNE 16798-1, 2020** CAT II (PPD 10%)		
			Max	Mean	Min	Max	Mean	Min	% over upper limit	% under lower limit	**% weekly hours in discomfort**	% over upper limit	% under lower limit	**% weekly hours in discomfort**
IES 1	A3	Southeast Class	17.9	14.8	11.2	21.4	20.6	19.5	0 %	5 %	5 %	0 %	**70 %**	**70 %**
		Northwest Class				21.3	20.5	19.7	0 %	2 %	2 %	0 %	**86 %**	**86 %**
IES 2	A3	Southeast Class				22.5	21.4	20.3	0 %	0 %	0 %	0 %	15 %	15 %
		Northwest Class				23.3	21.5	20.4	0 %	0 %	0 %	0 %	17 %	17 %
IES 3	B4	Southeast Class	25.6	18.1	10.2	25.3	23	20.5	0 %	4 %	4 %	0 %	17 %	17 %
		Northwest Class				24.3	21.5	18.7	0 %	**31 %**	**31 %**	0 %	**61 %**	**61 %**
IES 4	B4	Southeast Class				27.1	24.6	22.3	13 %	0 %	13 %	0 %	0 %	0 %
		Northwest Class				25.7	23.8	21.3	0 %	0 %	0 %	0 %	3 %	3 %
IES 5	B3	East Class	25.6	18.2	10.6	25.8	23.7	18.9	0 %	6 %	6 %	0 %	13 %	13 %
		West Class				24.7	23.2	18.5	0 %	5 %	5 %	0 %	15 %	15 %
IES 6	C4	East Class	19.1	14.1	7.2	24.3	22.1	19.9	0 %	0 %	0 %	0 %	15 %	15 %
		West Class				24.4	22.5	20.3	1 %	0 %	1 %	0 %	1 %	1 %

The most relevant values are shown in bold type.

4 CONCLUSIONS

This research follows a statistical approach for the analysis of the archetypes of public secondary schools in Andalusia, a large region in southern Spain where different variants of the Mediterranean climate can be found. After clustering according to different parameters, up to 39 archetypes were obtained with a distribution of between 7 and 9 centers for each of the 5 most representative climate zones. The most significant parameters show that, in all the representative climate zones of the region, the centers are organized following the CCC (Class-Corridor-Class) typology. In addition, 41 % of the sample was built before 1979 and therefore was not in compliance with any regulations related to energy efficiency or ventilation. Furthermore, given that 53% of the sample was built between 1979 and 2006, under the NBE CT-79 regulations, mechanical ventilation systems are present in 5% of this sample. The field study conducted in 6 of these archetypal centers, under winter conditions, results in generally good values for IAQ parameters, obtaining maximum CO_2 concentration values between 1126 and 1147 ppm and a maximum daily percentage of hours above the 1000 ppm of 22% in zone B4. These good results are mainly due to the COVID continuous natural cross-ventilation protocols in place during the monitoring period. Although this requirement for natural ventilation to achieve indoor air quality in classrooms should have produced unfavorable results for hygrothermal comfort, the fact is, that in general, except in climate zone A3, low results are obtained for the percentage of hours of discomfort, mainly due to the unusually high winter temperatures.

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