Interreg Sudoe

ClimACT

ACTING FOR THE TRANSITION TO A LOW CARBON ECONOMY IN SCHOOLS: DEVELOPMENT OF SUPPORT TOOL

ENVIRONMENTAL AND ENERGY PERFORMANCE OF CLIMACT SCHOOLS

FOR A LOW CARBON ECONOMY

JANUARY 2018

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INTRODUCTION

Climate change is one of the most important environmental impacts that earth is being targeted, being the main cause excessive resources consumption and reliance on fossil fuel leading to CO_2 emissions. Huge reductions should be made to these emissions to limit catastrophic impacts of climate change.

LOW CARBON ECONOMY (LCE)

The implementation of a LCE, by incorporation complementary approaches such as energy efficiency, smart growth initiatives, transportation control measures, energy-efficient product procurement and resources conservation, conducts to important environmental, economic and social benefits. It reduces private and external costs and contributes for the accomplishment not only of energy related targets but also of the 3rd priority objective defined by the 7th Environment Action Program 'to safeguard the Union's citizens from environment-related pressures and risk to health and well-being'.

WHY LCE IN SCHOOLS?

1. Educational sector' buildings consume a significant amount of the total energy consumed across Europe. They represent more than 12% of the tertiary building sector consumption, accounting for an estimated 15Mtoe annually. Energy bills are typically the second largest expenditure category for schools. It is imperative for schools to reduce energy-related expenditures, without affecting educational operations, by applying procurement-related and behavioral-related measures.

2. Many energy efficiency investments pay for themselves quickly but are not realized in educational sector due to short knowledge about energy and environment performance, tight budget to make investments to reduce energy-related expenditures, lack of information about national and European financial support mechanisms and regulatory barriers.

3. Educational sector has enormous raise awareness potential. With the proper support, education can empower pupils with knowledge about climate change and sustainable energy and ensure they grow up knowing how to protect the environment with cemented robust energy-aware behaviors that can pave the way towards a sustainable future and to ensure the realization of the critical future EU targets.

CLIMACT PROJECT

WHAT IS THE CLIMACT PROJECT?

The main objective of this project is to support the transition to a LCE in schools. It develops and implements tools and methodologies to support schools managers, energy and environment players and students in the identification of intelligent solutions for schools management that consider energy efficiency, renewable energy use, respect for the environment, private and external costs, financial support mechanisms and human behaviors.

CLIMACT METHODOLOGY

ClimACT methodology is based on a systematic methodology conducting to a LCE in 39 pilot schools to demonstrate that the developed tools in the framework of the project lead to an effective transition to a LCE, to significant cost reduction and to quantifiable resources savings around Sudoe region

MAIN ACTIONS:

Develop decision support tools

Develop decision support tools that will assess and identify sustainable solutions for schools, based on intelligent resource management, renewable energy and behavior change

Create educational tools

Create educational tools to raise awareness in low-carbon, assisted by information and communication technologies

Generate new business models

Generate new business models and new management strategies for schools

Establish a thematic network

Establish a thematic network in the SUDOE region, driven by a Living Lab methodology, which will raise awareness and training and will foster a communication framework between end-users and stakeholders

ENVIRONMENTAL AND ENERGY PERFORMANCE

Environmental and energy performance was assessed based on audits in schools in order to reduce resources consumption and respective associated costs and CO_2 emissions.

The "reference baseline" of schools were defined by means of different Key Performance Indicators (KPIs) as a function of:

- information and inputs collected in pre-audits, through the pre-audit check-list (building characteristics, location, equipment, activities, behaviours, occupation profiles, etc.);
- information collected in audits, through on-site measurement campaigns;
- information obtained through the application of a behaviour questionnaire applied to students, teachers and administrative staff.

This report presents the results obtained for 7 sectores.

ENVIRONMENTAL AND ENERGY SECTORS CHARACTERIZATION

ENERGY	Energy audits evaluated the energy consumption from the last three years (2014, 2015, and 2016), and the associated CO_2 emissions.
WATER	Water audits evaluated the water consumption from the last three years (2014, 2015, and 2016), and the associated CO_2.
WASTE	Waste audits quantified the volume of waste produced divided by categories: disposed waste, composted-organic waste, reused waste and recycled waste.
TRANSPORTS	Transports audits analysed the users behaviour based on the transport mode used in the home-school path, quantifying CO_2 emissions, and also based in the quantification of diferent parking spaces (electric and bicycle) in schools, and the public transport network nearby schools.
GREEN SPACES	Green spaces audits assessed the green areas, the use of chemists and resources consumption associated to the green areas maintenance, and the CO_2 emissions and sequestration.
GREEN PROCUREMENT	Green procurement audits evaluated the electric and electronic equipment labelling, the consumption of recycled paper, the training in green procurement and eco-driving, and the preference for food with biological certificate and local suppliers.

INDOOR AIR QUALITY	IAQ and comfort audits were performed in selected rooms to be representative of the building in terms of size, number of occupants and activities, furnishings or equipment that can release pollutants to the indoor air. Main indoor pollutants were identified and analysed.

CLIMACT SCHOOLS

Audits were performed in 39 ClimACT schools from Sudoe region: 9 schools from Portugal - 5 located in Loures, 1 in Lisbon, 2 in Matosinhos, and 1 in Vila Nova de Gaia; 13 schools from Spain – 8 located in Seville, 1 in Málaga, 2 in Madrid, and 2 in Alcalá de Hernares; 9 schools from France located in La Rochelle, and 9 schools from Gibraltar (see Figure 1).

All schools levels are represented: 15 primary schools, 10 middleschools, 13 secondary schools, and 4 universities/high levels of education.

The name of each school is not showed in this report, but the schools were informed about their reference number.

ClimACT Schools:

Primary schools and kindergarten:
- PT: S2
- SP: S10-S13, S20
- FR: S26-S31
- GB: S32, S34

Middle schools:
- PT: S1-S4
- SP: S18
- GB: S33, S35

Secondary schools:
- PT: S5, S7
- SP: S14, S15, S16, S17, S21, S22
- FR: S24, S25
- GB: S36, S37

Universities/High levels of education:
- PT: S6
- FR: S23
- GB: S38, S39

Figure 1- Location and educational level identification of the ClimACT schools

TRANSPORTS

The schools performance regarding the transport sector was assessed based on the KPIs and scores presented in Table 1 and Table 2.

Table 1 - KPIs for the transports sector.

Sector	KPI designation	KPI calculation
Transports	Charging stations for electric cars per student	$KPI_{T1} = \frac{\text{no. of charging stations for eletric cars}}{\text{no. of students}}$
	Parking places for bicycle per student	$KPI_{T2} = \frac{\text{no. of parking places for bicycle}}{\text{no. of students}}$
	Public Transports per hour	KPI_{T3} = no. of public transports per hour within a 1000 radius
	CO_2 annual emissions per student	$\mathbf{PE}_i = \frac{(\#_{\text{never}} \times 0 + \#_{\text{almost never}} \times 1/3 + \#_{\text{almost always}} \times 2/3 + \#_{\text{always}} \times 1) \times \text{no. of people of the school}}{\text{no. of people that answered the questionnaire}}$ Where: *i* = transport mean (motorbike; car; boat; tram; train; subway; bus; bicycle; on foot); PE_i = person equivalent of the transport mean *i*. $\mathbf{CO_{2\,i} Emissions} = \sum_i (\mathbf{FE}_i \times \mathbf{PE}_i) \times \textbf{daily average distance} \times 22 \times 10$ Where: $CO_{2\,i}$ Emissions = Annual emissions associated to the transport mean *i*. **FE_i = emission factor of the transport mean *i* [1].** $KPI_{T4} = \frac{\sum_i CO_{2\,i}\text{ Emissions}}{\text{no. of students}}$

Table 2 - Transports scores

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Transports	Charging stations for electric cars	$S_{T1} = \frac{KPI_{T1} \times 5}{1.05 \times \max(KPI_{T1})}$	Without charging stations	Highest KPI_{T2} found plus 5%	1
	Parking places for bicycle	$S_{T2} = \frac{KPI_{T2} \times 5}{1.05 \times \max(KPI_{T2})}$	Without parking places	Highest KPI_{T3} found plus 5%	1
	Public Transports	$S_{T3} = \frac{KPI_{T3} \times 5}{1.05 \times \max(KPI_{T3})}$	Without public transports	Highest KPI_{T4} found plus 5%	1
	CO_2 annual emissions	$S_{T4} = 5 - \frac{\text{school emissions} \times 5}{\text{emissions of 100\% of students going by car}}$	100% of the students go by car	100% of the students go on foot or by bicycle	2

PARAMETERS ASSESSED

- *Parking characteristics*
- *Public transports network*
- *School community behaviour*
- *CO_2 emissions from daily commuting to school*

PARKING CHARACTERISTICS

The parking characteristics of the ClimACT schools was assessed based on the:

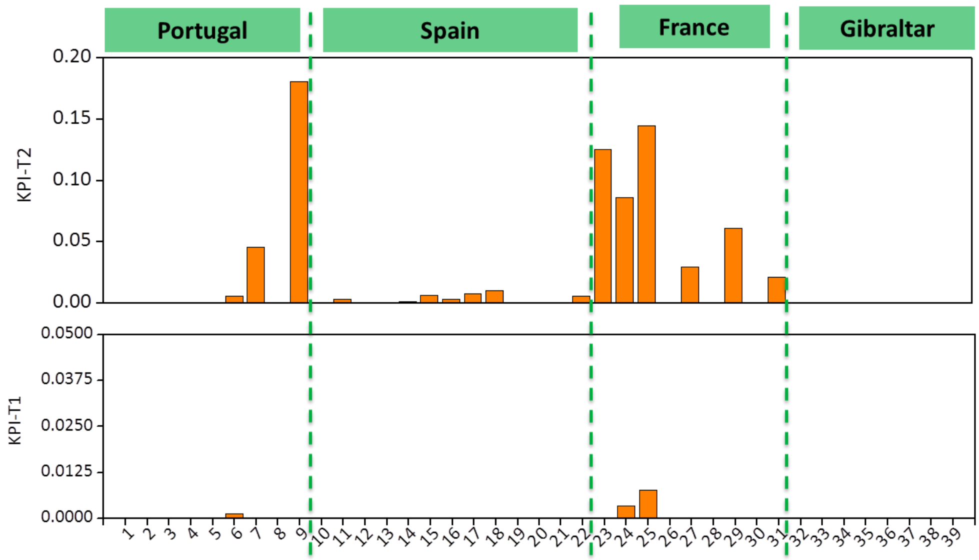
- Number of parking spaces at school or periphery (up to a 100m radius)
- Number of parking spaces to charge electric cars at school or periphery (up to a 100m radius)
- Number of parking spaces for bicycles at school or periphery (up to a 100m radius)

From the 39 ClimACT schools, only 3 (1 in Portugal and 2 in France) have charging stations for electric cars.

44% of the schools are equipped with parking places for bicycles. French schools have the highest number of parking places for bikes, varying between 220 and 1715 parking places per school. The behaviour questionnaire showed that it is also in France that the bicycles are more frequently used by the school community for the home-school commuting. Two schools from Portugal have also a good number of parking places for bicycles (S7-32 and S9-30). However, this fact doesn't impact on the number of people that use bicycle (that is in fact very small). This means that besides the parking places it is necessary to built safe cycle lanes (that do not exist nearby the Portuguese ClimACT schools) and to invest in awareness campaigns to change behaviours.

Gibraltar schools don't have results due to the non-existance of available data for charging stations for electric cars and parking places for bicycle.

Results presented in Figure 2 shows that it is necessary to improve parking for electric cars and bicycles in all countries.



KPI-T1 - No. of parking spaces for **electric cars** at school or periphery (up to a 100m radius)/student
KPI-T2 - No. of parking spaces for **bicycles** at school or periphery (up to a 100m radius)/student

Figure 2 – Parking characteristics of the 39 ClimACT schools.

The average value for the KPI-T1 and KPI-T2 are, respectively 0.0 parking places to charge electric cars per student, and 0.02 parking places for bicycles per student.

Parking score

Figure 3 shows that French schools present the highest parking scores (range score: 0-4.3), followed by Portuguese schools (range score: 0-2.4) and Spanish schools (range score: 0-0.1). The average of the transport score is 0.44 indicating that there is a large space for improvement in the ClimACT schools.

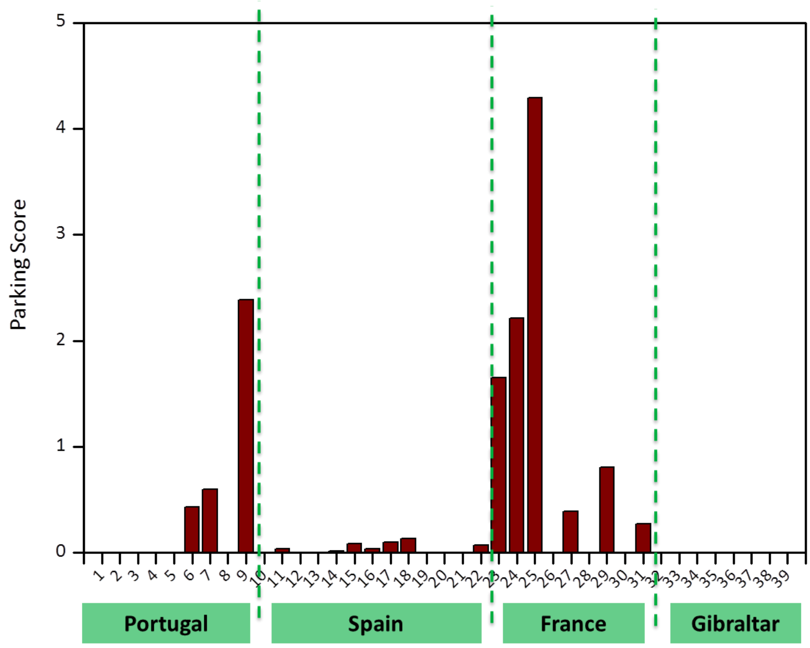


Figure 3 - Parking Score for the 39 ClimACT schools.

PUBLIC TRANSPORT NETWORK

The public transport network of the ClimACT schools was assessed based on the:

- Number of stops in the periphery of the schools
- Number of transports passing daily (1000m radius)
- Number of transports passing daily during rushing hour (1000m radius)
- Distance from the school to the nearest transport stop (m)

Figure 4 shows the number of transports stops and the number of public transports passing per hour within a radius of 1000 m (KPI-T3). 82% of the schools (32 schools) have a bus stop within a radius of 1000 m, 21% (8 schools) have a train stop, and 5% (2 schools) have a subway stop. Tram and boat are not available for ClimACT schools. In average, the number of available bus stops is 24 in Portugal, 11 in Spain and France and 1 in Gibraltar.

KPI-T3 indicates that the Portuguese and French schools have the highest transports frequency per hour (Portuguese schools: 25, French schools: 20, Spanish schools: 12).

Some data is missing due to the non existence of available data for Gibraltar schools.

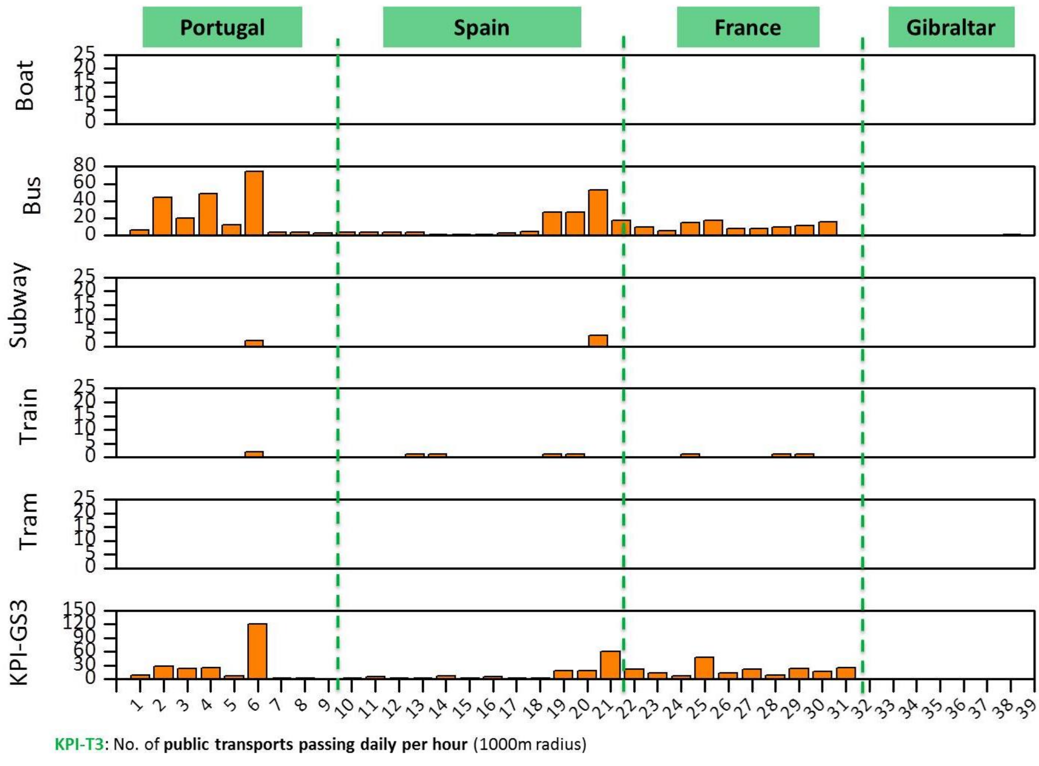


Figure 4 – Number of public transports passing nearby the 39 ClimACT schools

PUBLIC TRANSPORT NETWORK SCORE

Figure 5 shows that Portuguese schools have higher scores (average: 0.98, range score: 0.04-4.76), followed by French schools (average: 0.79, range score: 0.28-1.87) and Spanish schools (average: 0.47, range score: 0.08-2.43). Gibraltar doesn't have a score due to the non existance of data available. The average of the public transport network score is 0.71.

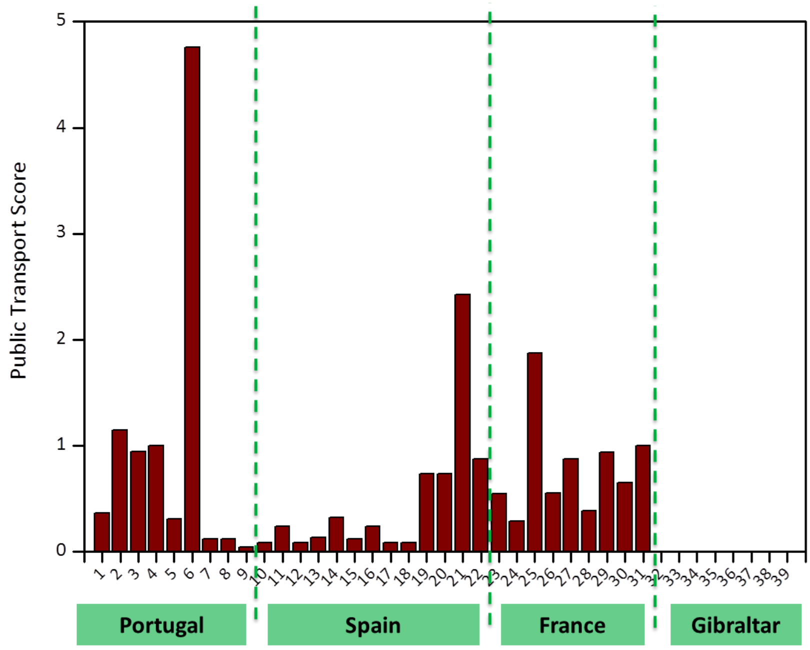


Figure 5 – Public transport network score for the 39 ClimACT schools

USERS BEHAVIOUR

The daily commuting behaviour of the schools' community of ClimACT schools was assessed by the application of the behavioural questionnaire to students, teachers and staff. They answered about the frequency they use the different transport means, the distance between home and school and if they practice car sharing . Figure 6 presents the frequency for the use of each transport mean and Figure 7 resume the information by using the person equivalent for each transport mean.

Data is missing for some schools in Gibraltar.

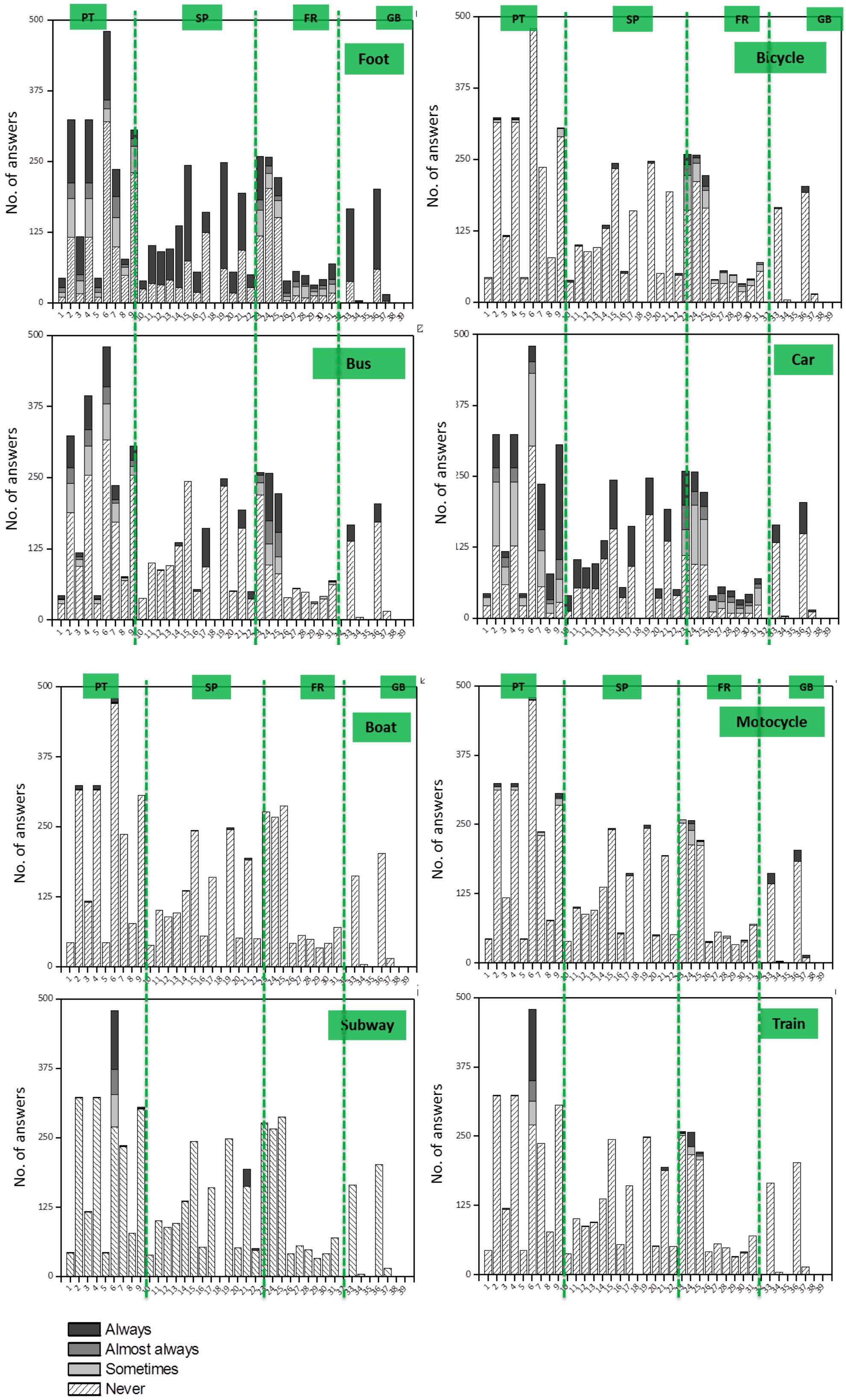


Figure 6 – Transports means used for daily commuting in the 39 ClimACT schools

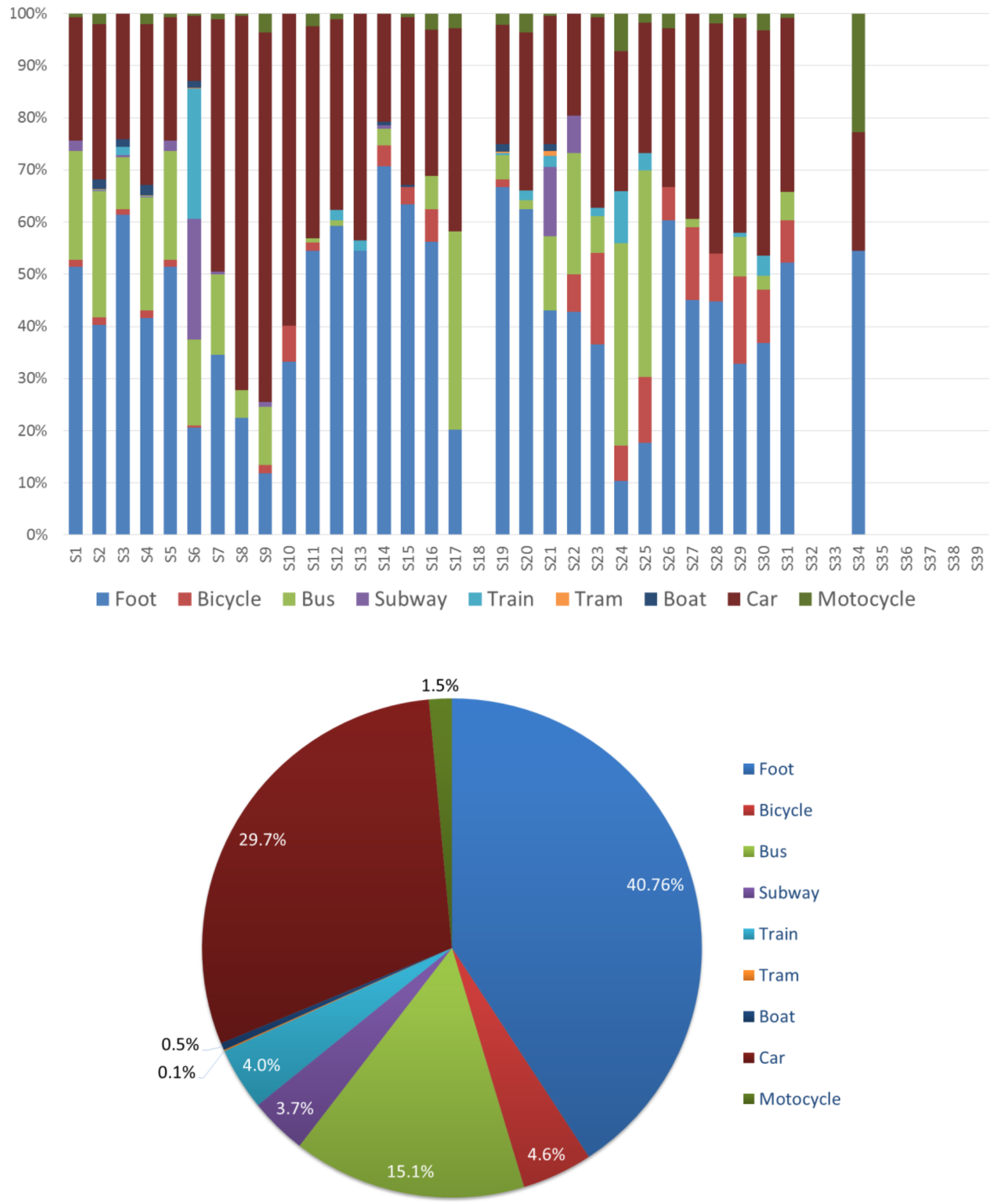


Figure 7 - Percentage of transport use in each school. Values based on person equivalente.

Results shows that the majority of the students go to school by foot (average: 41%), followed by car (30%) and bus (15%). The use of the difference transports means depends on the region and on the level of the school. 12% of the French students use bicycle for the daily commuting wherease in Portugal and Spain only 1% and 2%, respectively, go to school by bike. Besides the diferences of ages between the schools' students, the transport mean with high accession are the same (foot, car, bus, in descending order), but in the secondary schools and universitites the percentagem of adhesion is higher. It was also observed that the distance between the schools and home, that is usually larger in schools with older students, also influences the choice of the transport mean.

The annual CO_2 emissions per student (KPI-T4) was estimated and represented in Figure 8.

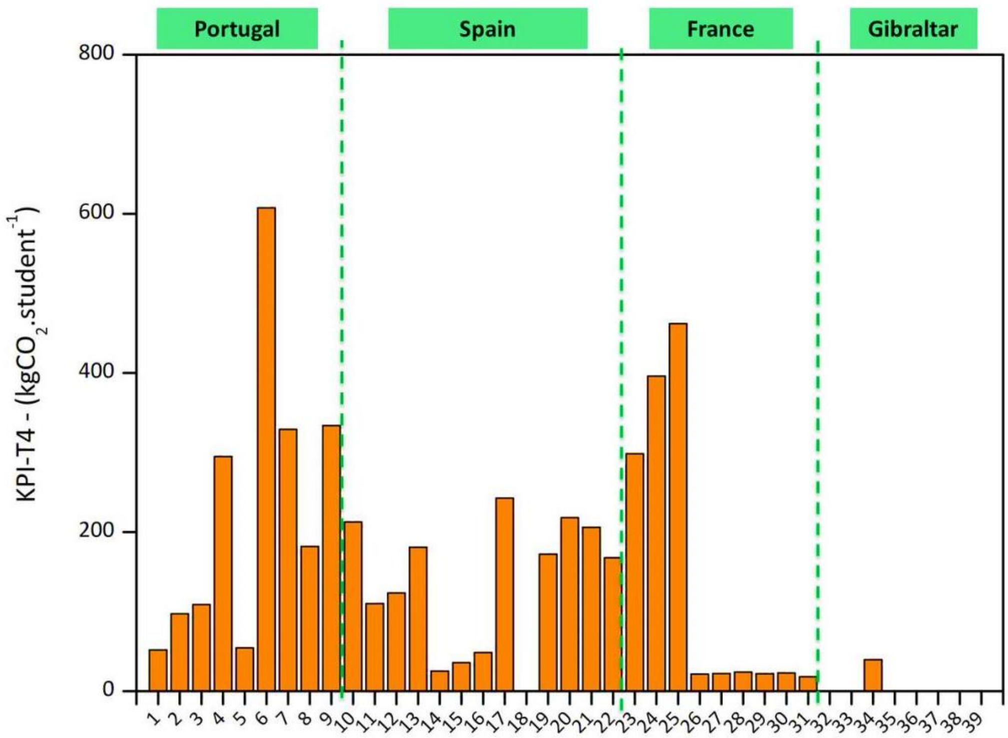


Figure 8 - Annual CO_2 emissions per student

According to the results, the schools from Portugal presented the highest annual CO_2 emissions (average: 607 $kgCO_2.student^{-1}$), followed by the French schools (average: 462 $kgCO_2.student^{-1}$) and Spanish schools (average: 243 $kgCO_2.student^{-1}$). The Portuguese school 6, which is an university, presented the highest CO_2 emissions due to the highest distances between school and home. In comparison with other higher educational institutions (S23, S38 and S39), the S6 is the university with higher CO_2 emissons. The Portuguese school S4 has also high CO_2 emissions. This can be due to the variability of the transport mean used, being the bus, the boat, the car and the moto highly used, in comparison with other schools.

In France the CO_2 emissions are higher in schools S23, S24 and S25. The reason for this fact is the diffence of the schools' eduacional levels, being these three high schools and the others primary schools.

For Gibraltar schools, there was only one school with results, and for that it has the highest annual CO_2 emissions, with a value of 39 $kgCO_2.student^{-1}$.

USERS BEHAVIOUR: ANNUAL CO_2 EMISSION SCORE

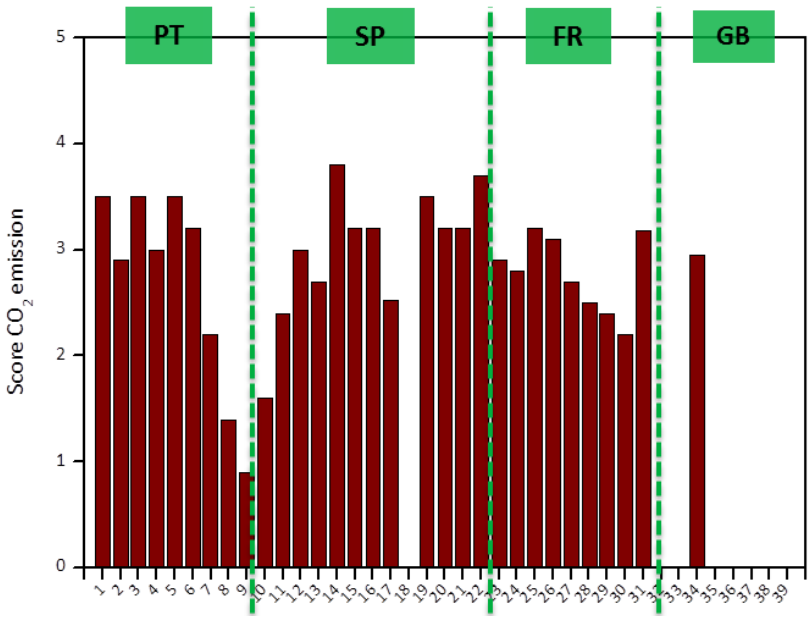


Figure 9 - Annual CO_2 transport emission score for the 39 ClimACT schools

Figure 9 shows that Spanish schools have highest average CO_2 emissions score (average: 3.0, range score: 1.6-3.8), followed by French schools (average: 2.9, range score: 02.2-3.2) and Portuguese schools (average: 2.7, range score: 0.9-3.5). Gibraltar only have a score for one school due to the non existance of available data. The Spanish school 18 doesn't have a score once the school community didn't answered the behavioural questionnaire. The average of the CO_2 transport emission score is 2.8.

TRANSPORTS FINAL SCORE

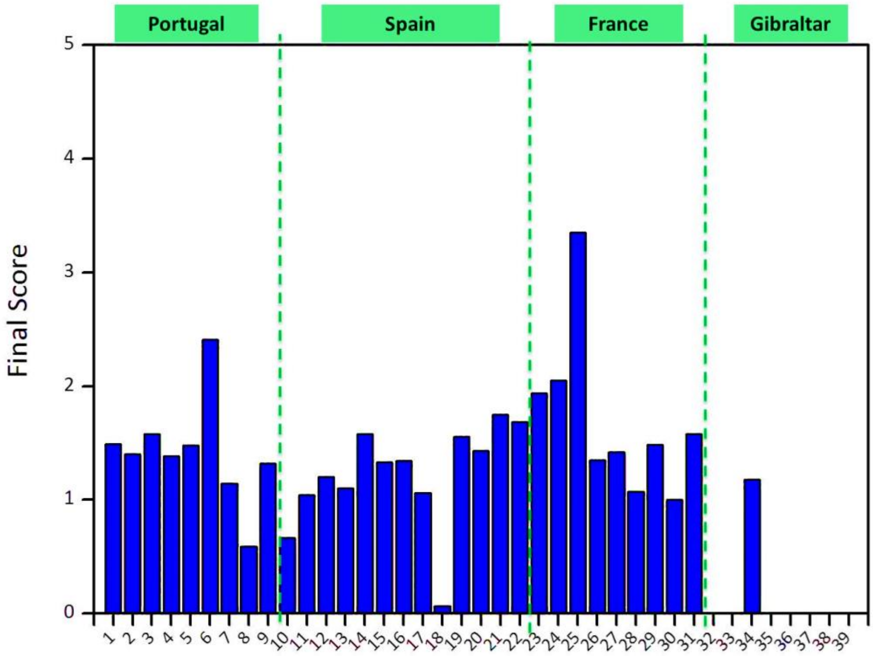


Figure 10 - Final score for the transport sector

The performance of the transport sector was assessed based on the individual scores of:

- Charging stations for electric cars
- Parking places for bicycles
- Public transports
- CO_2 annual emissions

According to Figure 10 French schools have the best performance (average: 1.70, range score: 1.00-3.40), followed by the Portuguese schools (average: 1.40, range score: 0.60-2.40), and the Spanish schools (average: 1.30, range score: 0.70-1.80).

In order to improve the schools performance in what concerns the students mobility and their behaviours, measures should foccus on the improvement of mobility infrastructures surrounding the schools, and on the change of the schools' community behaviours. Some of these measures not only depend on the schools' community but also on the local governmental and public transports entities, such as the increase of cycle lanes, bicyle parking, charching for electric cars and improvement of the public transports.

Green Procurement

Green procurement sector was assessed based on the KPIs and scores presented in Table 3 and Table 4.

Table 3 - KPIs for the green procurement sector

Sector	KPI designation	KPI calculation
Green Procurement	Equipment efficiency	$KPI_{GP1} = \frac{\text{no. of equipment A+ or higher EU energy label}}{\text{total no. of equipments}}$
	Paper used per student per year	$KPI_{GP2} = \frac{\text{total ammount of paper}}{\text{student}}$
	Quantity of recycled paper used per school	$KPI_{GP3} = \frac{\text{quantity of recycled paper}}{\text{total quantity of paper}}$
	Biological food	$KPI_{GP4} = \frac{\text{quantity of food with biological certificate}}{\text{total quantity of food}}$
	Eco driving certification	$KPI_{GP5} = \frac{\text{no. of employees with eco} - \text{driving certificates}}{\text{total no. of employees}}$
	Training in green procurement	$KPI_{GP6} = \frac{\text{no. of employees with training in green procurement}}{\text{total no. of employees}}$
	Local suppliers	$KPI_{GP7} = \frac{\text{no. of local suppliers}}{\text{total no. of suppliers}}$

Table 4 – Green procurement scores

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Green Procurement	Equipment efficiency	$S_{GP1} = KPI_{GP1} \times 5$	Without certified equipment	100% of certified equipment	1
	Paper consumption	$S_{GP2} = 5 - \frac{KPI_{GP2} \times 5}{\max(KPI_{GP2})}$	Highest KPI_{GP2} found	Without use	1
	Recycled paper	$S_{GP3} = KPI_{GP3} \times 5$	Without recycled paper	100% recycled paper	1
	Biological food	$S_{GP4} = KPI_{GP4} \times 5$	Without training	100% trained employees	0.25
	Eco-driving certification	$S_{GP5} = KPI_{GP5} \times 5$	Without certified employees	100% certified employees	0.25
	Training in green procurement	$S_{GP6} = KPI_{GP6} \times 5$	Without certified employees	100% certified employees	0.25
	Local suppliers	$S_{GP7} = KPI_{GP7} \times 5$	Without local suppliers	100% local suppliers	0.25

PARAMETERS ASSESSED

- *Equipment efficiency*
- *Paper used*
- *Recycled paper used*
- *Biological food*
- *Eco-driving certification*
- *Training in green procurement*
- *Local suppliers*

Figure 11 shows the results obtained for the green procurement parameters assessed for the ClimACT schools. Their performance was estimated based on the 7 KPIs shown in Figure 11.

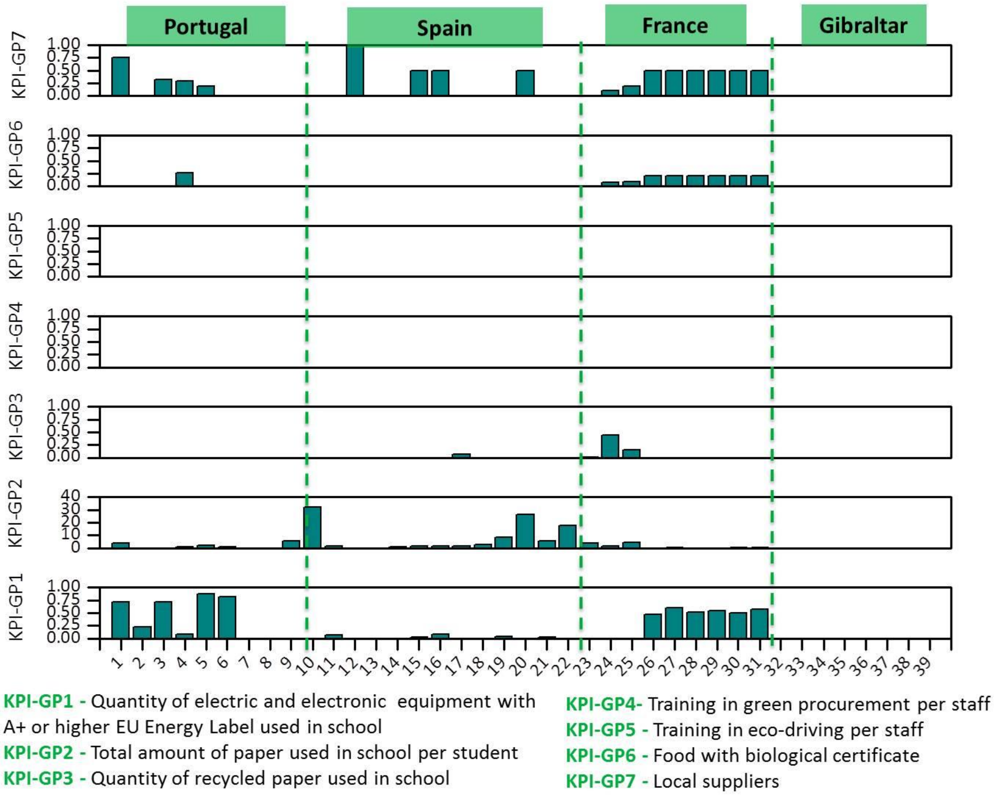


Figure 11 - Green procurement performance for the 39 ClimACT schools

Results show a weak investment in training on green procurement and eco-driving.

The consumption of paper is higher in Spanish schools (average KPI-GP2: 7.6) followed by the Portuguese schools (average KPI-GP2: 1.5) and French schools (average KPI-GP2: 1.2). It was verified that only a few number of schools use recycled paper, and in a low amount. These schools are one Spanish school (S17) and three French schools (S23-S25). The schools from Portugal and France present the electric equipment with better efficiency (average KPI-GP7: 0.38, and 0.36, respectively) followed by Spanish schools (in average KPI-GP7: 0.02).

The French schools present the highest values for KPI-GP7, which is related with local suppliers, (average: 0.4), followed by the Spanish and Portuguese schools (average: 0.19, and 0.18, respectively).

GREEN PROCUREMENT FINAL SCORE

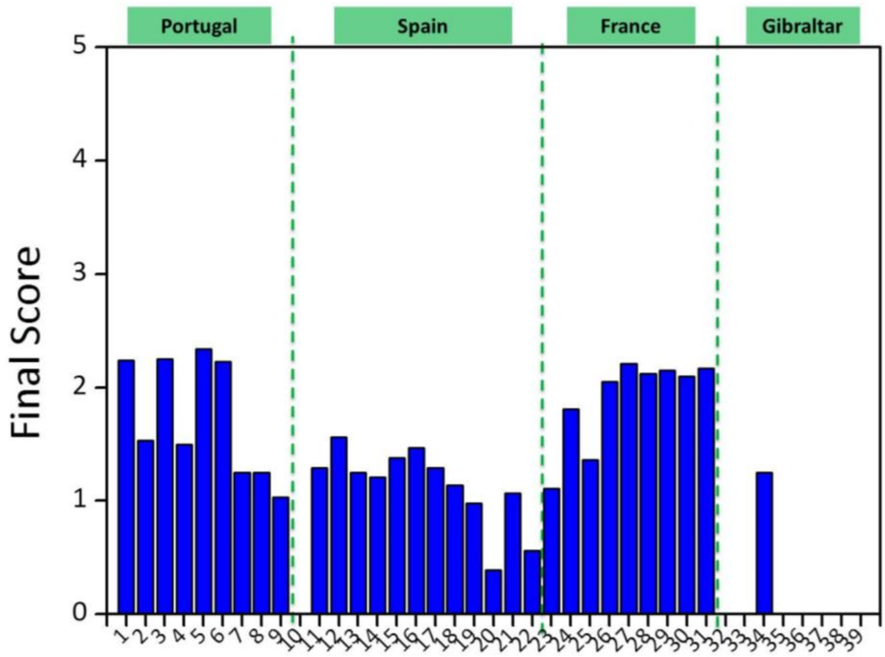


Figure 12 - Final score for the green procurement sector

The performance of the green procurement sector, based on the individual scores, is presented in Figure 12. Results show that the French schools have the best performance (average: 1.9, range score: 1.1-2.2), followed by the Portuguese schools (average: 1.7, range score: 1.0-2.3), and by the Spanish schools (average: 1.0, range score: 0.0-1.6).

To enhance the improvement of this sector, actions should be made. These actions can be shaped based in two directions: to the school community and to the school green procurement management. This means that it is important to promote awareness actions where all the schoolar community will be sensitized to the importance of green procurement. These actions can be made by gamification, for example. Furthermore, this awareness will contribute to do good choices in what concerns school acquisitions. In this case, schools' managers habits and behaviours will change towards the selection of equipments with higher energy efficiency, the increase of the use of recycled paper, the improvement of the schoolar workers training in eco-driving and green procurement, and the preference of purchase biological products from local suppliers.

GREEN SPACES

The schools performance regarding the green spaces sector was assessed based on the KPIs and scores presented and scores presented in

Table 5 and Table 6.

Table 5 - KPIs calculation for the green spaces sector

Sector	KPI designation	KPI calculation
Green Spaces	Trees per non-covered area	$KPI_{GS1} = \frac{\text{no.of trees}}{\text{non-covered area}}$
	Trees per student	$KPI_{GS2} = \frac{\text{no. of trees}}{\text{no. of students}}$
	Green area per non-covered area	$KPI_{GS3} = \frac{\text{green area}}{\text{non} - \text{covered area}} \text{ x } 100$
	Green area per student	$KPI_{GS4} = \frac{\text{green area}}{\text{no. of students}}$
	Annual CO_2 sequestration per non-covered area	$KPI_{GS5} = \frac{\text{no. of trees} \times SR_{\text{dominant species}} + \text{lawn area} \times SR_{\text{lawn}}}{\text{non} - \text{covered area}}$ Where: SR = sequestration rate [2].
	Annual usage of chemicals per green area	$KPI_{GS6} = \frac{\text{quantity of fertilizers and pesticides}}{\text{green area}}$
	Annual CO_2 emissions per non-covered area	$KPI_{GS7} = \frac{\text{Fuel} \times FE_{\text{fuel}} + \text{water} \times FE_{\text{water}} + \text{electicity} \times FE_{\text{electricity}}}{\text{non} - \text{covered area}}$ Where: FE = factor emission [1].

Table 6 - Green procurement scores calculation

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Green Spaces	Trees per non-covered area	$S_{GS1} = \frac{KPI_{GS1} \times 5}{1.05 \times \max(KPI_{GS1})}$	Without trees	Highest KPI_{GS1} found plus 5%	0.5
	Green area per non-covered area	$S_{GS2} = \frac{KPI_{GS3} \times 5}{1.05 \times \max(KPI_{GS3})}$	Without green area	Highest KPI_{GS3} found plus 5%	0.5
	Annual usage of chemicals per green area	$S_{GS3} = 5 - \frac{KPI_{GS6} \times 5}{\max(KPI_{GS6})}$	Highest KPI_{GS4} found	Without chemicals	1
	Annual CO_2 sequestration per non-covered area	$S_{GS4} = \frac{KPI_{GS5} \times 5}{1.05 \times \max(KPI_{GS5})}$	Without sequestration	Highest KPI_{GS5} found plus 5%	1
	Annual CO_2 emissions per green area	$S_{GS5} = 5 - \frac{KPI_{GS7} \times 5}{\max(KPI_{GS7})}$	Highest KPI_{EV7} found	Without emissions	1

PARAMETERS ASSESSED

- *Green areas*
- *Use of chemists, water and energy in green areas maintenance*
- *CO_2 sequestration and emission*

Figure 13 shows the results obtained for the green spaces parameters assessed for the ClimACT schools.

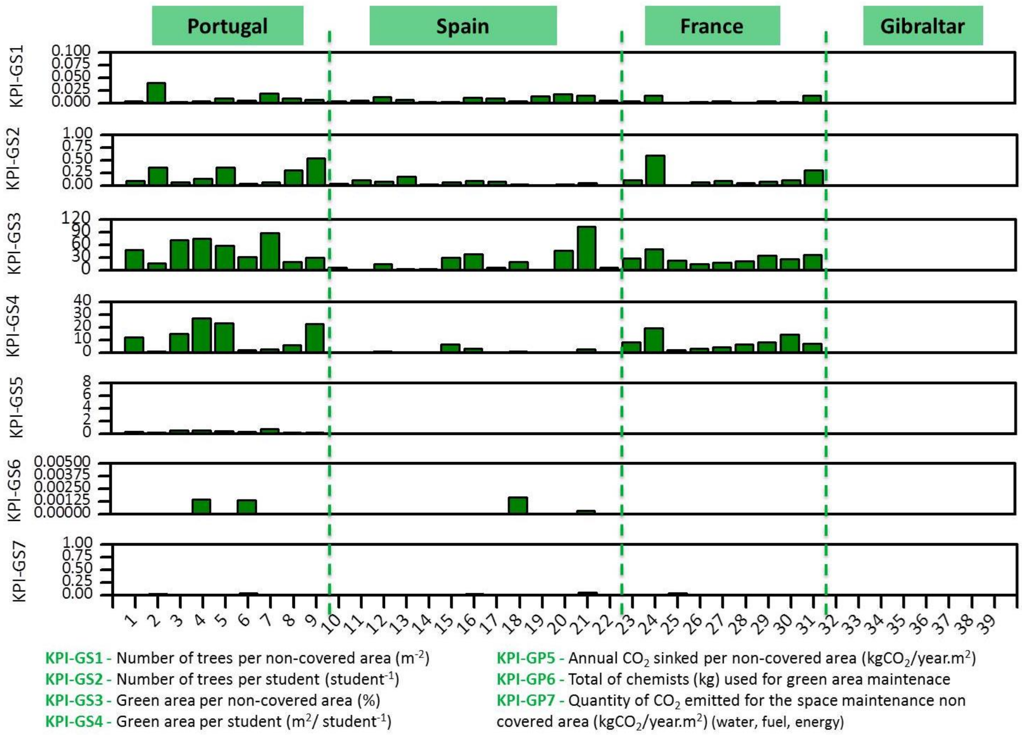


Figure 13 - Green spaces performance for the 39 ClimACT schools

The Portuguese schools, followed by the French schools presented the best results concerning the number of trees per area/per student (KPI-GS1, and KPI-GS2), and the green areas per area/per student (KPI-GS3, and KPI-GS4).

The Portuguese schools also have the highest score regarding the assessment of the green area and number of trees (calculated based on the trees per non-covered area and green area per non-covered area) with an average of 1.8, followed by the Spanish schools (average: 1.0) and French schools (average: 0.02). For the Gibraltar schools there is no data available to calculate this score.

Observing the schools' best performance in what concerns the annual CO_2 sinked per non-covered area (KPI-GS5), the Portuguese schools have the best performance (average: 0.43 $kgCO_2/m^2$.tree.year), followed by the Spanish (average: 0.04 $kgCO_2/m^2$.tree.year), and the French schools with the lowest results (average: 0.03 $kgCO_2/m^2$.tree.year). The variability of the results are due to the diference of the predominant trees species, and, consequently, the sequestration factor (SF) of the species (Table 7). In Portuguese and French schools, there are a higher number of planted trees in comparison with Spanish schools, however, their SF are lower than the SF for the trees in spanish schools. Gibraltar schools have no available data.

Table 7 – Species of the predominant schools' trees and their CO_2 sequestration factor

School	Species of the predominant trees	Sequestration Factor (kg CO2/tree and year)
Portuguese Schools	Meek Pine	5.03
	Pine	3.18
	Olive tree	2.46
	Sycamore tree	21.81
	Acer pseudoplatanus	5.75
	Quercus	5.29
Spanish Schools	Fraxinus	6.34
	Citrus sinensis	1.77
	Olea europaea	2.46
	Aligustre	2.46
	Pinus Pinea	5.03
	Tipuana tipu	7.43
	Varied (pinus y viburnus)	5.03
	Platanus hispanica	10.82
	Eriobotrya japonica	4.58
French Schools	Pinus pinea	5.03
	Fraxinus ornus	4.77
	Tilia platyphyllos	8.85
	Celtis occidentalis	5.99
	Quercus cerrioides	7.81
	Acer platanoides	8.72
	Tila europeae	5.80
	Ligustrum vulgare	3.07

It is recommended to privilege the use of autochthonous tree species, with the high SF if possible, and, at the same time, to increase the number of trees per area.

In general, schools do not use chemists for green area maintenance (KPI-GS6), being the Portuguese (S4 and S6) and Spanish (S18 and S21) schools the ones that use chemists but in small quantities. The use of water, fuel and energy consumption for green areas maintenance (KPI-GS7) are very low or nonexistent.

GREEN SPACES FINAL SCORE

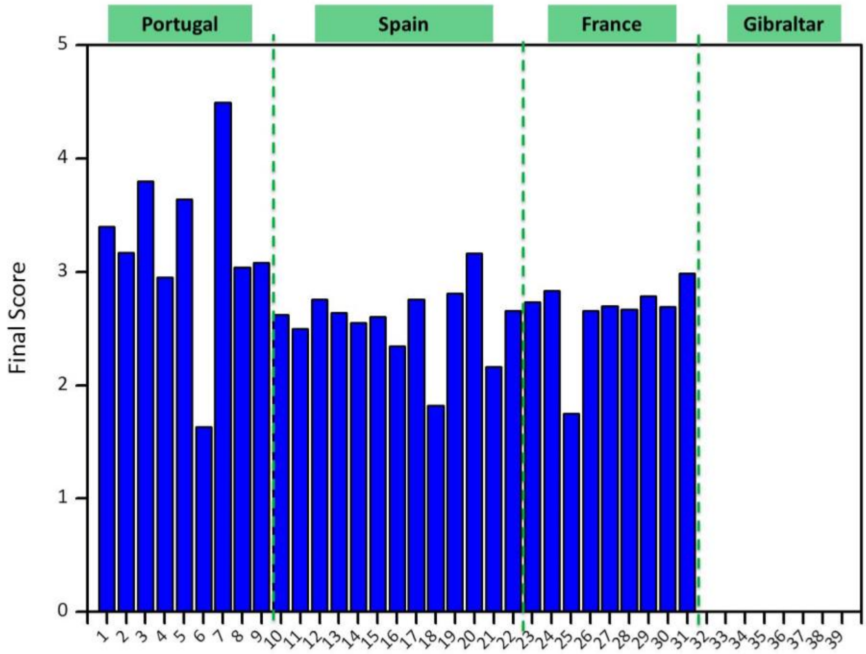


Figure 14 - Final score for the green spaces sector

Figure 14 shows that Portuguese schools have better performance (range score: 1.63-4.49, average: 3.25), followed by the French schools (range score: 1.75-2.95, average: 2.65) and the Spanish schools (range score: 1.83-3.17, average: 2.57).

The green spaces sector is a sector with huge potential of improvement. Some measures can be implemented in order to schools achieve a better performance. These measures are directed to the capacity of the schools to reduce CO_2 emissions in the green spaces maintenance, and in improve these spaces to increase their CO_2 sequestration capability.

The CO_2 emissions reduction in the green spaces maintenance can be achieved by the use of natural resources, as example the use of a drop irrigation and retention system, the use of manual tools and/or the use of equipments powered by renewable energy in order to exclude the use of fuels.

At the improvement of the CO_2 sequestration by the green spaces is associated the increase of the existant green species: trees, gardens, and flowerbeds. It is important to do a good management of these areas between the number of the trees and trees' species. Species with higer sequestration factor should be prioritized. However, in order to preserve the local ecossystem, autochthonous trees species should be selected.

All of these actions can be successfully implemented if exists awareness of the schoolar community in what concerns green spaces contribution to the local and global air quality and their power to contribute to its improvement.

ENERGY

The schools performance regarding the energy sector was assessed based on the KPIs and scores presented in scores presented in

Table 8 and Table 9.

Table 8 - KPIs calculation for the energy sector

Sector	KPI designation	KPI calculation
Energy	Energy consumption per useful area	$\mathrm{KPI_{E1}} = \frac{\sum_i \text{annual consumption of eletricidade}_i + \sum_j (\text{annual consumption of fuel}_j \times \text{density}_j \times \mathrm{FC}_j)}{\text{useful area}}$ Where: *i* = type of electricity (provide by the grid; onsite produced); *j* = type of fuel (diesel; LPG; natural gas); FC_j = conversion factor to kWh of fuel *j* [9].
	Energy consumption per student	$\mathrm{KPI_{E2}} = \frac{\sum_i \text{annual consumption of eletricidade}_i + \sum_j (\text{annual consumption of fuel}_j \times \text{density}_j \times \mathrm{FC}_j)}{\text{student}}$ Where: *i* = type of electricity (provide by the grid; onsite produced); *j* = type of fuel (diesel; LPG; natural gas); FC_j = conversion factor to kWh of fuel *j* [9].
	Percentage of renewable energy production	$\mathrm{KPI_{E3}} = \frac{\text{Renewable energy produced for onsite comsumption} + \text{renewable energy production sold to grid}}{\sum_i \text{annual consumption of eletricidade}_i + \sum_j (\text{annual consumption of fuel}_j \times \text{density}_j \times \mathrm{FC}_j)}$ Where: *i* = type of electricity (provide by the grid; onsite produced); *j* = type of fuel (diesel; LPG; natural gas); FC_j = conversion factor to kWh of fuel *j* [9].
	Energy costs per useful area	$\mathrm{KPI_{E4}} = \frac{\text{energy annual costs}}{\text{useful area}}$
	Energy costs per student	$\mathrm{KPI_{E5}} = \frac{\text{energy annual costs}}{\text{nr of studentss}}$
	CO_2 annual emissions	$\mathrm{KPI_{E6}} = \frac{(\text{electricity consumption} - \mathrm{REP} \times \mathrm{GL}) \times \mathrm{FE}_e + \sum_i (\text{consumption of fuel}_i \times \text{density}_i \times \mathrm{FC}_i) \times \mathrm{FE}_i)}{\text{nr of students}}$ Where: *i* = type of fuel (diesel; LPG; natural gas); FC_i = conversion factor to kWh of fuel *i* [9] FE_e = emission factor associated to electrical energy consumption [10]. FE_i = emission factor associated to fuel *I* [10]. REP = Renewable electrical production GL = Grid losses

Table 9 - Energy scores calculation

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Energy	Energy consumption per useful area	$\mathrm{S_{E1}} = \frac{(\max(\mathrm{KPI_{E1}}) - \mathrm{KPI_{E1}}) \times 5}{\max(\mathrm{KPI_{E1}}) - \min(\mathrm{KPI_{E1}}) \times 0.95}$	Highest $\mathrm{KPI_{E1}}$ found	Lowest $\mathrm{KPI_{E1}}$ found less 5%	$\frac{1}{2}$
	Energy consumption per student	$\mathrm{S_{E2}} = \frac{(\max(\mathrm{KPI_{E1}}) - \mathrm{KPI_{E1}}) \times 5}{\max(\mathrm{KPI_{E1}}) - \min(\mathrm{KPI_{E1}}) \times 0.95}$	Highest $\mathrm{KPI_{E2}}$ found	Lowest $\mathrm{KPI_{E2}}$ found less 5%	$\frac{1}{2}$
	Percentage of renewable energy production	$\mathrm{S_{E3}} = \mathrm{KPI_{E3}} \times 5$	0% renewable energy	100% renewable energy	1
	Energy costs per useful area	$\mathrm{S_{E4}} = \frac{(\max(\mathrm{KPI_{E5}}) - \mathrm{KPI_{E5}}) \times 5}{\max(\mathrm{KPI_{E5}}) - \min(\mathrm{KPI_{E5}}) \times 0.95}$	Highest $\mathrm{KPI_{E4}}$ found	Lowest $\mathrm{KPI_{E4}}$ found less 5%	$\frac{1}{2}$

	Energy costs per student	$S_{E5} = \frac{(\max(KPI_{E6}) - KPI_{E6}) \times 5}{\max(KPI_{E6}) - \min(KPI_{E6}) \times 0.95}$	Highest KPI_{E5} found	Lowest KPI_{E5} found less 5%	$\frac{1}{2}$
	CO_2 annual emissions	$S_{E6} = \frac{(\max(KPI_{E7}) - KPI_{E7}) \times 5}{\max(KPI_{E7}) - \min(KPI_{E7}) \times 0.95}$	Highest KPI_{E6} found	Lowest KPI_{E6} found less 5%	1

Parameters assessed

- *Energy consumption*
- *Energy cost*
- *Renewable energy*
- *Carbon emissions*

Energy consumption

To characterise the energy consumption of ClimACT schools, all possible energy sources were accounted. ClimACT schools use, not only electricity as energy source, but also use diesel, LPG, biomass pellets and natural gas. Besides that, some schools use renewable sources as solar thermal panels and photovoltaic panels to produce energy.

Since some energy sources are used for space or water heating it is necessary to use the lower heating value of each fuel source to evaluate the global energy consumption.

Figure 15 shows the energy consumption of all schools for each fuel source. Not only do schools have very different consumptions but also their energy mix is quite different. The main reason behind these differences are the type of school (primary, midlle, secondary and high level schools) and the number of students that attend the school. Gibraltar schools have no available data.

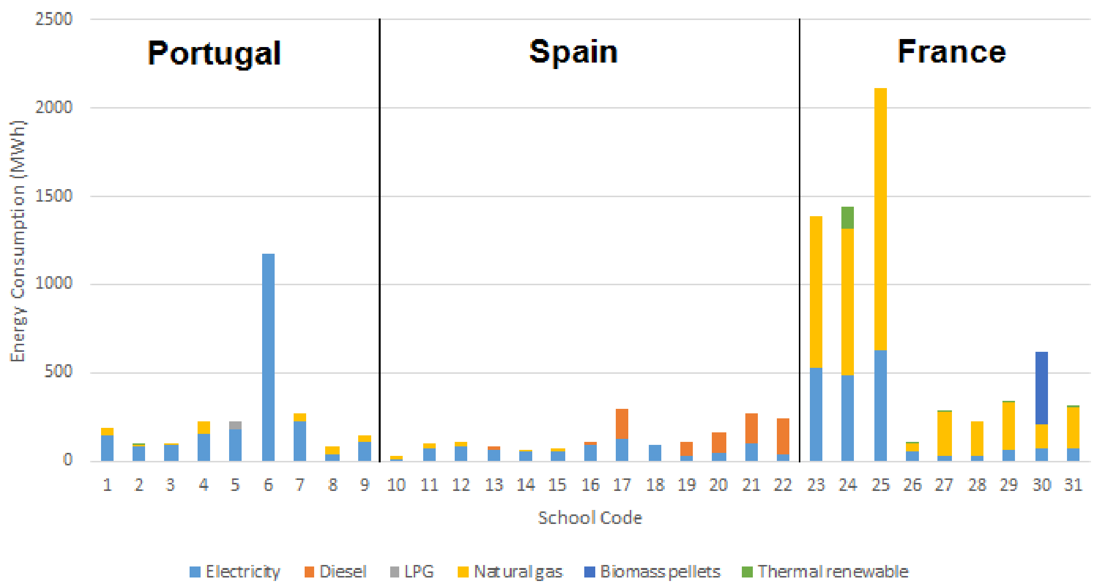


Figure 15 – Final energy consumption by source

ENERGY CONSUMPTION SCORES

The energy scores are based on the total energy consumption, the number of students and area of the school. The use of these two last indicators can help to reduce the impact of different conditions in the schools' energy consumption. The result is a more balanced score, that represents the real conditions with more accuracy.

In Figure 16, Portugal and Spain have similar scores across all schools but in France there is a big discrepancy in scores. The most obvious reason for the lower scores in France is the higher necessity of space heating due to lower winter temperatures, but it is not clear how some schools have such a low score compared to others. Gibraltar schools have no available data.

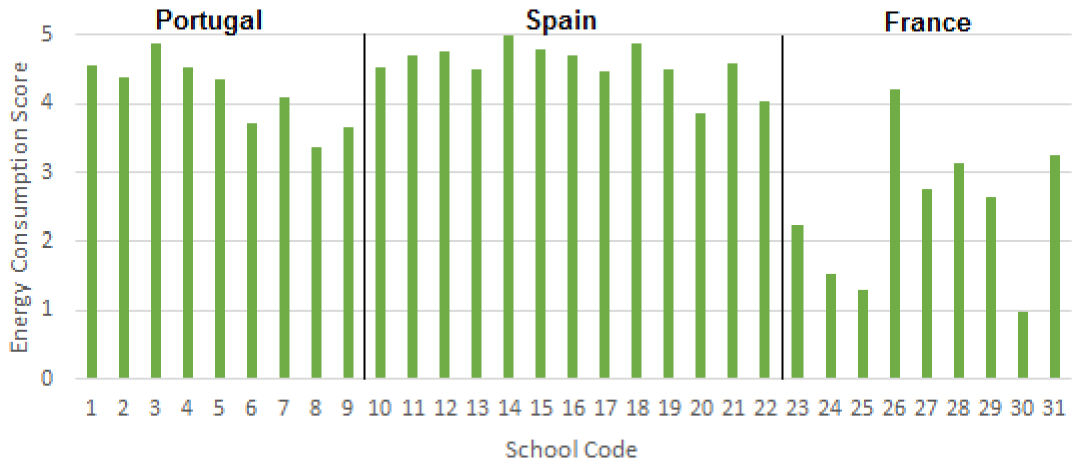


Figure 16 – Energy consumption scores

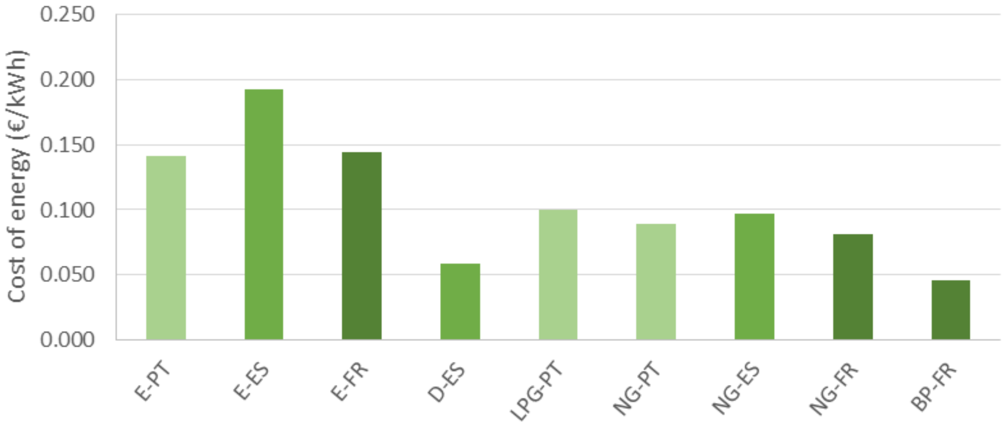
To improve these scores, schools should use more energy efficient equipment.

ENERGY COST

The energy cost is highly related with the energy consumption; a higher energy consumption is usually associated with a higher energy cost. The biggest difference between the KPI-E4 and KPI-E5 to the energy consumption KPIs (KPI-E1 and KPI-E2) is that some energy sources have a lower cost than other, benefiting the use of the sources with lower cost. Also, the different prices between countries and even within countries can benefit some schools.

In Figure 17 it is possible to see that electricity has the highest price per kWh, and the diesel and the biomass pellets have the lowest prices per kWh produced. In order to increase the energy cost KPIs (KPI-E4 and KPI-E5),To increase this KPI, schools should decrease the electricity consumption and favor other energy sources, especially the renewable energy sources which have no cost to run.

Gibraltar schools have no available data.



Legend: E-PT - Electricity Portugal E-ES - Electricity Spain E-FR - Electricity France D-ES - Diesel Spain LPG-PT - LPG Portugal NG-PT - Natural Gas Portugal NG-ES - Natural Gas Spain NG-FR - Natural Gas France BP-FR - Biomass Pellets France

Figure 17 – Cost of energy by source and country

Energy cost score

Just like the energy consumption, the energy cost was normalized to the number of occupants and building area in order to establish the score represented in Figure 18.

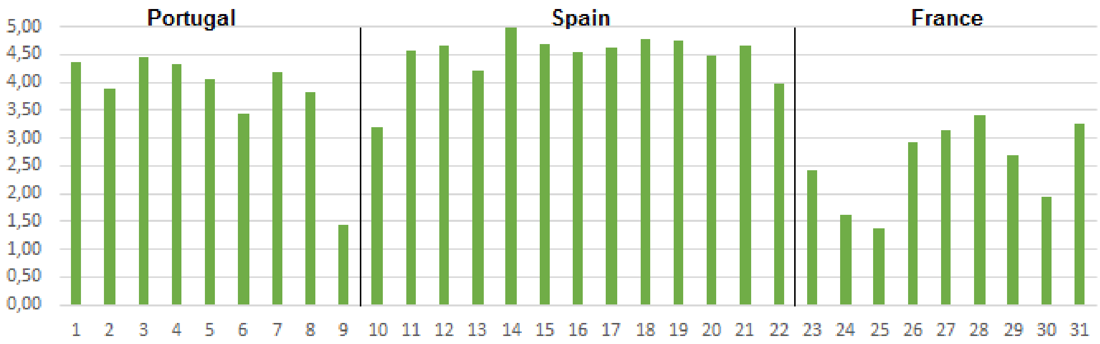


Figure 18 – Energy Cost Scores

Both Portugal and Spain have high scores for this KPI (with exceptions), but, again, France has the lower scores. The reason for these results is that the energy cost is not normalized for the energy consumption, meaning that buildings with high energy consumption reflect that with a high energy cost.

Renewable energy

Renewable energy KPI (KPI-E3) measure the amount of renewable energy produced by the each school, compared to the total energy consumption.

Renewable energy production is insignificant in all assessed schools. In Spain and Portugal, only one school had some renewable energy production through solar thermal panels used for DHW. Gibraltar and France lack data on renewable energy production but it is known that at least one of the schools in France uses photovoltaic panels to produce electricity and five other schools use thermal solar panels for DHW.

Renewable Energy Score

~~The renewable energy score is calculated by admitting that the best case scenario would be to produce all energy that is consumed, and that would allow to achieve a score of 5.~~

As there is only one school (S2) which has a score higher than 0, it is irrelevant to present these scores as they would not provide any valuable information. S2 score is 0.13, which is equivalent to more than 2 MWh per year. This can be seen as a first step to the use of renewable energies in schools, but a huge progress is necessary to achieve better results.

CO_2 Annual Emissions

CO_2 emissions associated with energy consumption is one of the most important KPI. ~~as the only reasons that lead someone to reduce energy consumption are the cost and the environmental impact~~. The KPI-E6 can be use as a simplified measure of the environmental impact associated with energy consumption.

Using the IPCC Emission Factor Database it is possible to construct

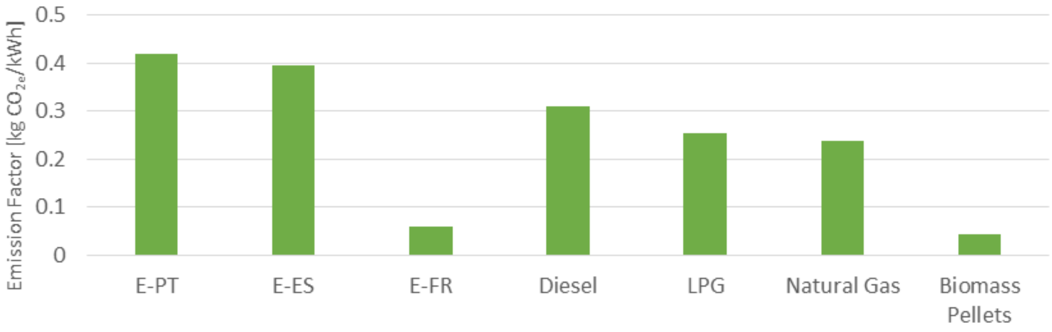


Figure 19, with the emission factors for every energy source in each country.

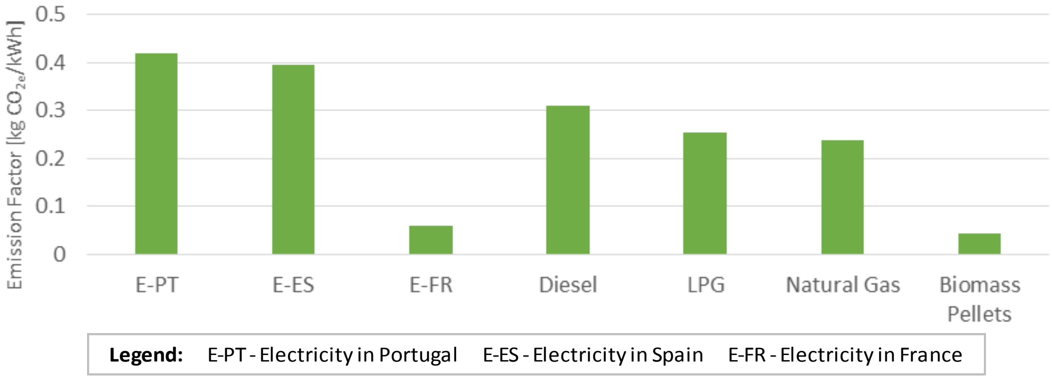


Figure 19 – CO_2 emissions for each energy source

This KPI can be increased with the use of renewable energy sources since these sources have no associated equivalent carbon dioxide emissions.

Other option is to use biomass pellets as a energy source. Biomass is often considered a carbon neutral energy source but IPCC considers that in terms of equivelant carbon dioxide is not totally neutral. Electricity in France is also close to be carbon neutral as most of the power generated in France comes from nuclear power plants.

CO_2 ANNUAL EMISSIONS SCORE

CO_2 annual emissions score (Figure 20) is calculated by taking into account the emission factor of each energy source and the energy consumption. This allows to obtain a equivalent mass of CO_2 emited by the use of energy. This score is normalized to the number of students in order to achieve a value that reflects one of the most important variables in schools.

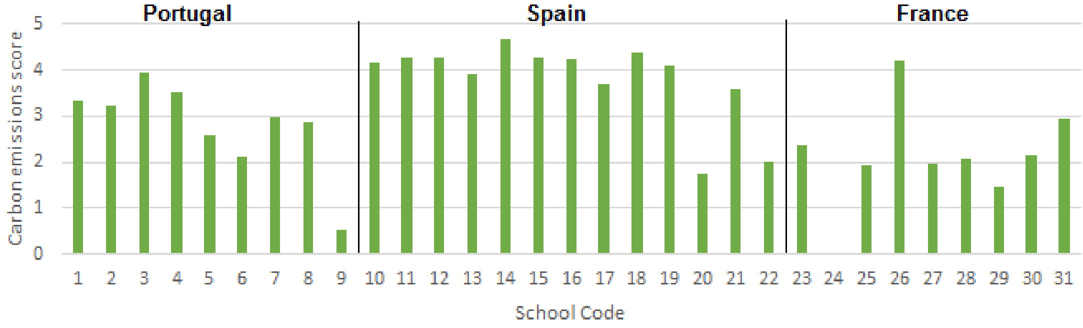


Figure 20 – Carbon Emission Scores

Unlike other KPIs, CO_2 is unbalenced across countries. This can be justified with the influence of two different factors: the energy comsumption per student and the energy mix of each school.

Due to the lack of energy sources with no emissions (renewables), the influence of the energy consumption per student should be higher than the influence of the energy mix. Nonetheless, the use of electricity in France, biomass pellets and renewable energy sources have a great potential to shift the values of this KPI.

Gibraltar schools have no available data.

ENERGY FINAL SCORE

The final energy scores can be seen in the following Figure 21.

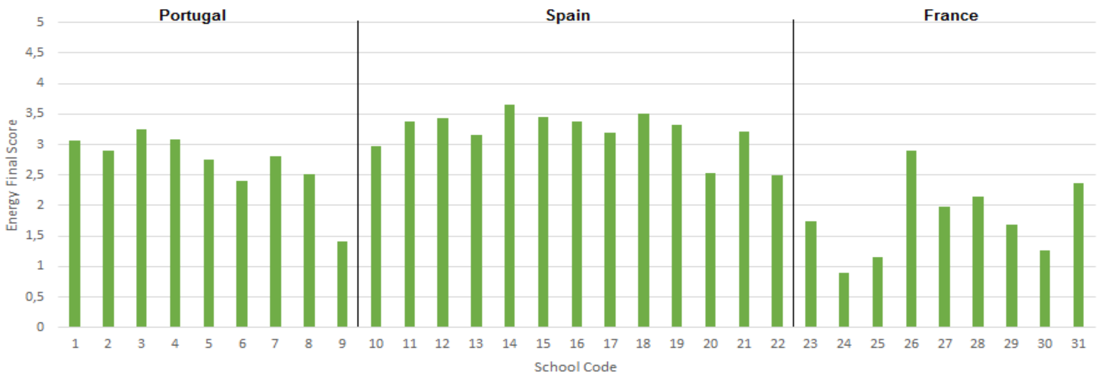


Figure 21 - Final score for the energy sector

According to this figure, French school have the lowest scores, while Spain schools have the highest scores. Because of the higher space heating needs in France it was espected that French schools energy score would be slightly lower than the rest.

These scores now set a baseline for schools to improve upon. Applying some of the recommendations detailed throughout this chapter will help to increase the scores and compare the different schools effort into making their school more eco-friendly.

WATER

The schools performance regarding the water sector was assessed based on the KPIs and scores presented in Table 10 and Table 11.

Table 3 - KPIs for the green procurement sector

Table 10 - KPIs calculation for the water sector

Sector	KPI designation	KPI calculation
Water	Water consumption per useful area	$KPI_{W1} = \frac{\text{annual water consumption}}{\text{useful area}}$
	Water consumption per student	$KPI_{W2} = \frac{\text{annual water consumption}}{\text{no.of students}}$
	Water costs per useful area	$KPI_{W3} = \frac{\text{annual water costs}}{\text{useful area}}$
	Water costs per student	$KPI_{W4} = \frac{\text{annual water costs}}{\text{no. of students}}$

Table 11 - Water scores calculation

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Water	Water consumption per useful area	$S_{W1} = \frac{(\max(KPI_{W1}) - KPI_{W1}) \times 5}{\max(KPI_{W1}) - \min(KPI_{W1}) \times 0.95}$	Highest KPI_{w1} found	Lowest KPI_{w1} found less 5%	0.5
	Water consumption per student	$S_{W2} = \frac{(\max(KPI_{W2}) - KPI_{W2}) \times 5}{\max(KPI_{W2}) - \min(KPI_{W2}) \times 0.95}$	Highest KPI_{w2} found	Lowest KPI_{w2} found less 5%	0.5
	Water costs per useful area	$S_{W3} = \frac{(\max(KPI_{W3}) - KPI_{W3}) \times 5}{\max(KPI_{W3}) - \min(KPI_{W3}) \times 0.95}$	Highest KPI_{w3} found	Lowest KPI_{w3} found less 5%	0.5
	Water costs per student	$S_{W4} = \frac{(\max(KPI_{W4}) - KPI_{W4}) \times 5}{\max(KPI_{W4}) - \min(KPI_{W4}) \times 0.95}$	Highest KPI_{w4} found	Lowest KPI_{w4} found less 5%	0.5

PARAMETERS ASSESSED

- *Water consumption*
- *Water cost*

The following Figure 22 shows the values obtained for each water KPI that were assessed.

Figure 22 – Results of all defined KPI's for the water sector

InFigure 22 – Figure 22 is possible to identify that Spanish schools are the ones that have higher score due to their low water consumption and low cost, followed by the Portuguese schools which have the highest water consumption on average, even when looking at consumption per student or consumption per useful area. French schools have the final scores raised due to their high water cost, something that is out of control for the schools but has an impact on their economical resources.

Despite it being hard to suggest specific measures to improve their performance, these results can be seen as an incentive for Portuguese and French schools to follow the example of the Spanish schools. An important issue in this field is that green areas, in some cases, are responsible for most of the water consumption, meaning that improving the irrigation systems the water consumption can be easily reduced. The other main water consumption area in schools are the toilets. The use of temporized taps and faucet aerators can reduce the water consumption.

WATER FINAL SCORE

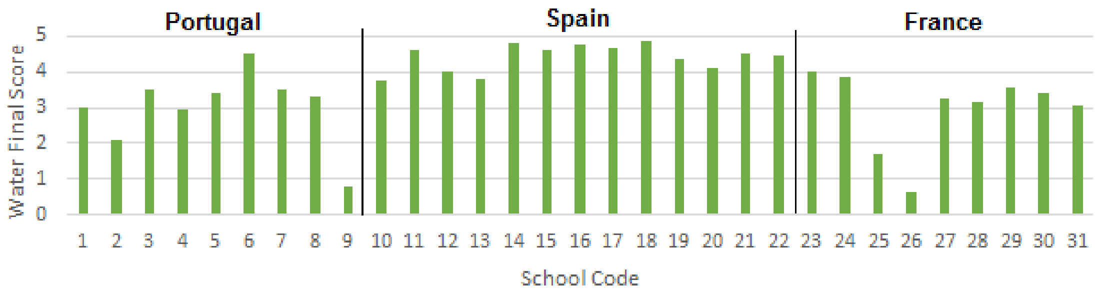


Figure 23 - Final score for water sector

Figure 23 shows the final water scores and just like it was seen before, the Spanish schools have excellent scores on this sector. This happens due to the score of 4.75 being given to the school that represents best scenario, and because this best scenario water consumption and cost is so close to other schools in Spain the scores of the water sector are very high.

According to these results, theschools from Portugal and France have a good margin to improve their performance, which could happen by improving good practices. Gibraltar has no data available to calculate the score.

WASTE

The schools performance regarding the waste sector was assessed based on the KPIs and scores presented in Table 12 and Table 13.

Table 12 - KPIs calculation for the waste sector

Sector	KPI designation	KPI calculation
Waste	Weekly production of urban solid waste (USW) per student	$\mathbf{KPI_{R1} = \frac{weekly\ production\ of\ USW}{no.\ of\ students}}$
	Weekly production of recyclables per student	$\mathbf{KPI_{R2} = \frac{weekly\ production\ of\ recyclable\ waste}{no.\ of\ students}}$
	Weekly production of reusables per student	$\mathbf{KPI_{R3} = \frac{weekly\ production\ of\ reusable\ waste}{no.\ of\ students}}$

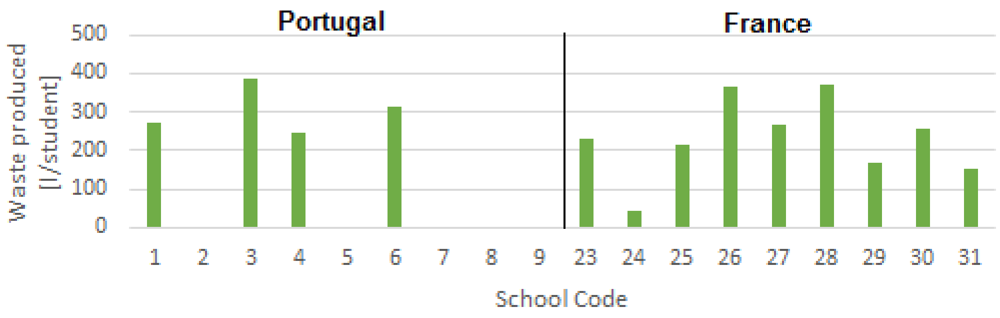
Table 13 - Waste scores calculation

Sector	Score designation	Score calculation	Less favourable scenario	More favourable scenario	Weighting for final score
Waste	Weekly production of urban solid waste (USW)	$S_{R1} = 5 - \frac{KPI_{R1} \times 5}{\max(KPI_{R1})}$	Highest KPI_{R1} found	$Min(KPI_{R1}-(KPI_{R2}+KPI_{R3}))$ less 5%	2
	Weekly production of recyclables	$S_{R2} = \frac{KPI_{R2} \times 5}{\max(KPI_{R2}) \times 1.05}$	Without recyclable waste	Highest KPI_{R2} found plus 5%	1
	Weekly production of reusables	$S_{R3} = \frac{KPI_{R3} \times 5}{\max(KPI_{R3}) \times 1.05}$	Without reusable waste	Highest KPI_{R3} found plus 5%	1

PARAMETERS ASSESSED

- *Waste produced*
- *Waste recycled*
- *Waste reused*

Figure 24 resumes the results obtained for each KPI in the waste sector, except the KPI of reused waste (KPI-R3).



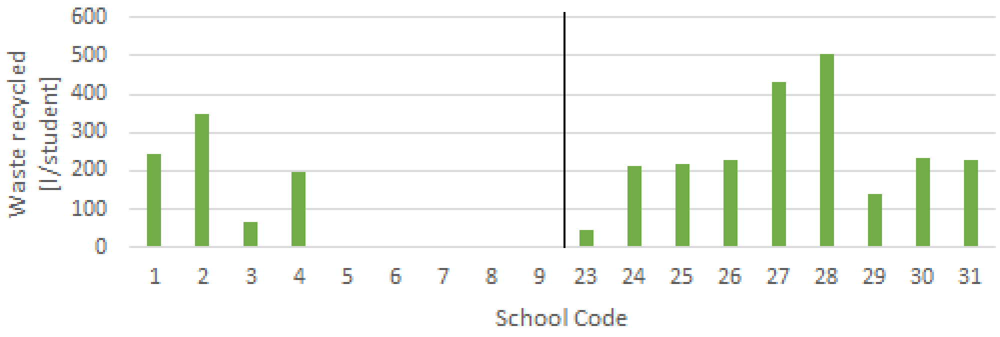


Figure 24 – Non-recycable and recyclable waste produced in each school

The total waste produced by schools is the sum of both KPIs (KPI-R1 and KPI-R2). The average waste produced by this sample of schools is near 11 liters per student every week. As it is a small sample it is difficult to compare and extract information about the waste sector but the fact is that French schools have a higher percentage of recycled waste. This could mean that they are more prone to recycling, besides their considerable larger amount production ofwaste.

The reused waste (KPI-R3) for every school assessed is zero, meaning that there is no reuse of waste products in schools. Schools from Spain and Gibraltar have no available data and some portuguese schools (S4-S9), which present a result of zero in both KPI-R1 and KPI-R2, have no available data as well.

WASTE FINAL SCORE

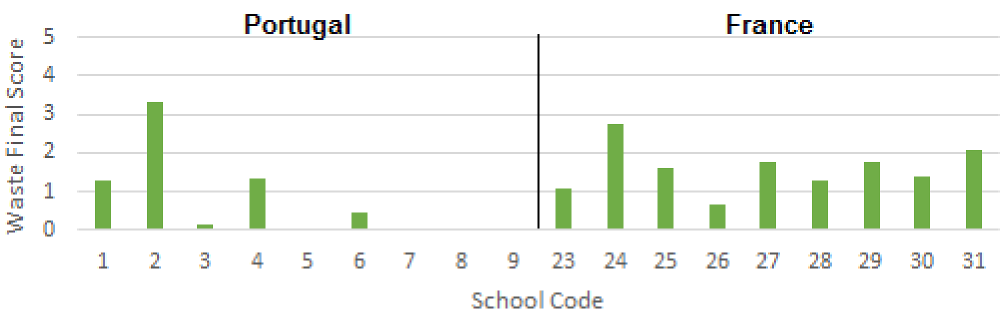


Figure 25 - Final score for the waste sector

Figure 25 shows the final scores of the waste sector. France schools have a lead in this sector, with scores of 0.3 points higher than the Portuguese schools. This reveales that, if Portuguese schools want to improve their performance they should increase the percentage of recycled waste.

INDOOR ENVIRONMENT QUALITY

MESAURED PARAMETERS

The schools performance regarding indoor environment quality was assessed based on the measurement of 24 pollutant concentrations, as well as temperature and relative humidity monitorings, in two selected classrooms of each school.

The concentrations of carbon monoxide (CO), carbon dioxide (CO_2), Total Volatile Organic Compounds (TVOC), fine airborne particles ($PM_{2.5}$), and coarse airborne particles (PM_{10}) were continuously monitored over 2 continuous school days in Portugal, Spain and Gibraltar, and over a full week including the week-end in France. The measurement timesteps were different for the contaminants and from one country to another, due to different technical characteristics and storage capacity of the instruments, but all were less than 5 minutes (5 s or 1 min for TVOC, CO, CO_2 and 1 minute for PM in Southern Portugal and France, 5 min and 2 min for all parameters in Northern Portugal and Spain, respectively). The mean concentrations during the occupancy period were considered to compute the KPIs and scores.

On the other hand, the concentrations of 10 specified VOC and 9 specified aldehydes were measured over one school week based on passive sampling and subsequent laboratory analysis. As results, those measurements return mean weekly concentrations including the periods when the classrooms are unoccupied.

Table 14 presents the guidelines (also called threshold limit values, TLV) that were selected to compute the KPIs and scores (see their definition in next section). In a general way, health-based guidelines considering long term exposures were selected. No relevant guideline could be found for propanal, isopentanal and benzaldehyde. On the other hand, only Lower Concentrations of Interest (LCI)[1] are available for butanal (650 µg/m^3), pentanal (800 µg/m^3) and hexanal (900 µg/m^3). These guidelines are nevertheless so high that it was considered to be not relevant to consider these chemicals in the definition of KPIs and scores. Finally, guidelines were set for only 18 over 24 pollutants investigated.

[1] LCI are health-based threshold limit values set by the EU Joint Research Centre that aim at the harmonization of mandatory labelling of material emissions in Europe

Table 14 - Pollutant investigated in the pilot schools, measurement method, and guideline

Pollutant	Measurement method	Relevant concentration C	Guideline	Unit	Comment
PM_{10}	Online	Mean during occupancy period	20	µg/m^3	This is the long term exposure health-based guideline set by the WHO. The portuguese TLV of 50 µg/m^3 is a management guideline
$PM_{2.5}$	Online	Mean during occupancy period	10	µg/m^3	This is the long term exposure health-based guideline set by the WHO. The Portuguese TLV of 20 µg/m^3 is a management guideline
CO	Online	Mean during occupancy period	6	ppm	10 µg/m^3 (8.7 ppm) is the guideline set by EU (Index project) for an 8h-exposure repeated each day of the week. The Portuguese value is lower and is therefore expected to be a long term guideline
TVOC	Online	Mean during occupancy period	600	µg/m^3	There are no health-based guidelines associated to TVOC since TVOC cannot figure out the health impact of VOCs. The portuguese management guideline of 600 µg/m^3 is proposed but all the IAQ audits should be performed using the portuguese instruments in order to ensure that the same thing is measured in all schools (especially the question with TVOC is to know which chemical equivalent is this concentration measured)
Formaldehyde	Passive sampler	Weekly average	30	µg/m^3	The Portuguese and French upper limits of 100 µg/m^3 for mandatory IAQ audits in schools are not health-based. 100 µg/m^3 is an extremely high concentration. On the other hand, the French health-based guideline of 10 µg/m^3 is extremely difficult to reach. As a way to be able to distinguish between schools regarding formaldehyde concentrations it is suggested to consider a TLV of 30 µg/m^3 which is management guideline set by the French Public Health Council for IAQ audits.
Acetaldehyde	Passive sampler	Weekly average	200	µg/m^3	200 µg/m^3 is the long-term exposure set by EU (Index project) for acetaldehyde. The French health-based guideline is 160 µg/m^3,

					also for a long term exposure
Acrolein	Passive sampler	Weekly average	0.8	µg/m^3	0.8 µg/m^3 is the French guideline for a long-term exposure. The Californian one is 0.35 µg/m^3
Benzene	Passive sampler	Weekly average	2	µg/m^3	The Portuguese management guideline of 5 is pretty high. It is suggested to consider the French health- based guideline of 2 µg/m^3, which corresponds to an ERU of 1 x 10^{-5}. Measurements made in French schools show that most concentrations are below this guideline.
Toluene	Passive sampler	Weekly average	250	µg/m^3	The Portuguese guideline. No guideline were set by the WHO or EU
Xylenes (m+o+p)	Passive sampler	Weekly average	200	µg/m^3	EU guideline (Index project) for a long term exposure. LCI are 500 µg/m^3 for each type
Trichloroethylene	Passive sampler	Weekly average	20	µg/m^3	The Portuguese guideline is 25 µg/m^3 but it is suggested to take the French one which is of 20 µg/m^3. It is health-based and corresponds to an ERU of 1 x 10^{-5}
Tetrachloroethylene	Passive sampler	Weekly average	250	µg/m^3	Portuguese, French and WHO guideline for a long-term exposure
Styrene	Passive sampler	Weekly average	250	µg/m^3	This is the EU health-based guideline (Index and LCI), which is very close to the Portuguese one (260 µg/m^3)
1,4-dichlorobenzene	Passive sampler	Weekly average	150	µg/m^3	150 µg/m^3 is the LCI set by EU-JRC. the Japanese guideline is 240 µg/m^3 for a long-term exposure.
α-pinene	Passive sampler	Weekly average	200	µg/m^3	200 µg/m^3 is the German guideline for a long-term exposure. No European or SUDOE country guideline exists, except the JRC LCI of 2500 µg/m^3.

DEFINITION OF KPIS AND SCORES

Indoor air quality (IAQ)

KPIs were defined for all contaminants *p* having a guideline (TLV_p) by :

$$KPI_p = \frac{C_p - TLV_p}{TLV_p}$$

That way, KPI_p values range from -1 when the concentration is 0 (best IAQ), to infinity when the concentration is far over the guideline. Negative values indicate that the concentration is less than the guideline, that is IAQ can be considered to be acceptable based on pollutant p. The distributions of KPIs in the two classrooms investigated were represented as radar or flow charts in the audit reports for schools as a way to provide both an overview and a comparison of IAQ in these classrooms (Figure 26).

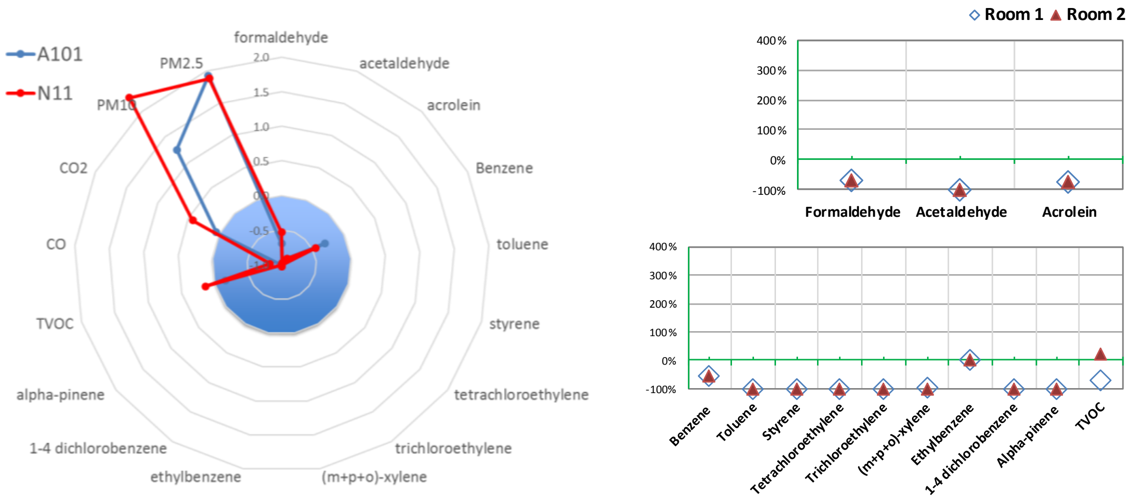


Figure 26 – Representation of IAQ KPIs in the audit reports for schools

The IAQ score ($0 \leq score_{IAQ} \leq 5$) was defined based on the number of concentrations over the guideline in the two classrooms investigated, that is:

$$Score_{IAQ} = 5 - 5\frac{\sum_p \delta_p}{32}$$

With $\delta_p = 1$ if $C_p > TLV_p$ and $\delta_p = 0$ otherwise.

Ventilation

CO_2 concentrations during the occupancy hours are a balance between the metabolic production by occupants, and the dilution by the air change rate. As a result, CO_2 concentrations during the occupancy period were used to define a ventilation score, $Score_{vent}$, which characterizes the amount of fresh air provided to the classroom by reference to the number of occupants. The ventilation score is defined as follows:

$Score_{vent} = 5 - ICONE$

With *ICONE* being an index which was developped by the French National Observatory of IAQ to assess room stuffiness based on perceived air quality resulting from bioeffluents emissions. It is defined by:

$$ICONE = \left(\frac{2.5}{log_{10}(2)}\right) log_{10}(1 + f_1 + 3f_2)$$

Where f_1 and f_2 are the percentages of CO_2 concentrations below 1000 ppm, and between 1000 and 1700 ppm, respectively, during the occupancy period.

The *ICONE* index lies in the range from 0 to 5, with 5 representing the highest level of air stuffiness. Therefore, here, $Score_{vent}$ also lies in the range from 0 to 5, but as for all environmental scores, 5 stands for the best possible performance.

Thermal comfort

The score for thermal comfort was defined based on the percentage ot temperatures between 20°C and 26°C during occupancy hours, corresponding to a class II comfort according to the EN 15251 standard. $Score_{comfort}$ is mathematically defined as:

$$Score_{comfort} = 5\frac{\sum_i \delta_i}{N}$$

With δ_i = 1 if 20°C ≤ T_i ≤ 26 °C and 0 otherwise, and *N* is the total number of temperature measurements during the occupancy period.

Thermal comfort results are nevertheless not discussed hereafter since the experimental period was not long enough to be representative of the actual hygrothermal conditions in the classrooms.

COMPLETION OF MEASUREMENTS

Figure 27 shows the percentage of measurements that were achieved and could be validated in the French, Portuguese, Spanish and Gibralatarian pilot schools. The following points can be highlighted:

Airborne particle concentrations are missing for 2 Portuguese schools, and were found to be irrelevant in two other ones. For technical reasons, airborne particle and TVOC concentrations were also monitored in only one classroom of several schools. On the other hand, outdoor $PM_{2.5}$ and PM_{10} concentrations were also measured in some schools, which is very helpful in interpreting the data.

Airborne particle and TVOC concentrations were monitored in only one classroom of each Spanish school. Any kind of monitoring was achieved in two of them.

Finally, any pollutant monitoring was achieved in Gibraltarian schools so far, but specified VOC and aldehyde were measured in all schools except one.

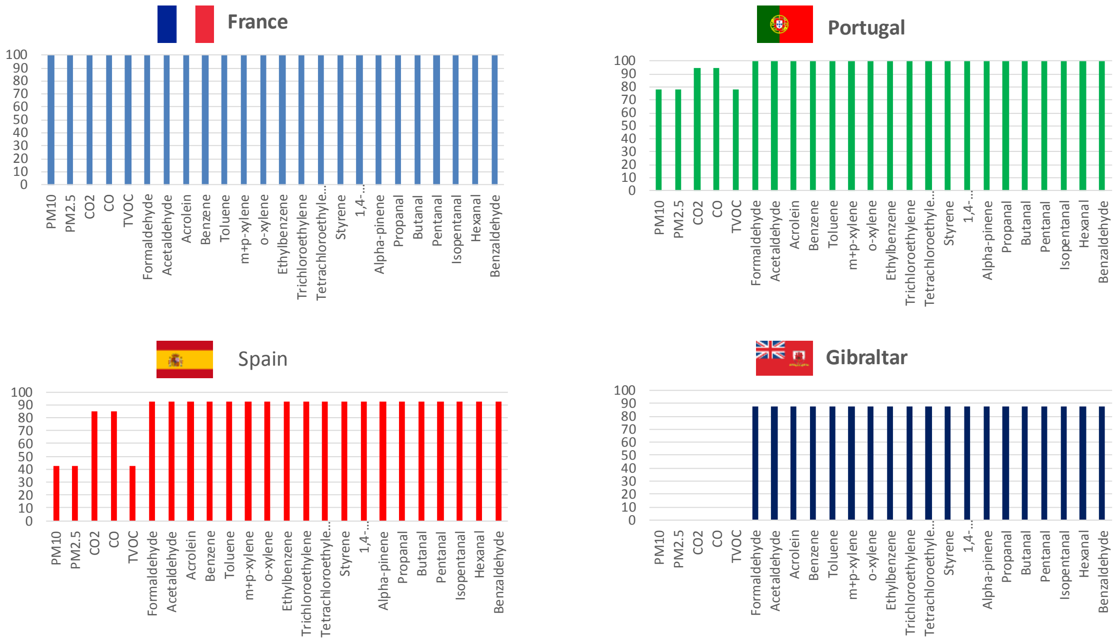


Figure 27 – Completion of IAQ measurements by country (%)

INDOOR AIR QUALITY RESULTS: POLLUTANTS WITHOUT GUIDELINE

The box-plots in Figure 28 graphically depict the concentration data of the six aldehydes that have no guideline through their 25th percentile (bottom of the box), 50th percentile (band inside the box = median), 75th percentile (top of the box), minimum and maximum (ends of the whiskers), and arithmetic mean (cross inside the box). The potential health impact of these concentrations cannot be assessed in the absence of toxicological data, but it can be noted that any concentration is over 30 µg/m^3, and most of them does not exceed few µg/m^3. The highest hexanal concentrations measured in France and Gibraltar nevertheless call for comments :

- In France, the highest concentration of 28 µg/m^3 is an outlier from the statistical point of view (it is plotted as an individual point on Figure 28). This mathematical situation is somewhat representative of the uniqueness of this data, from a practical point of view, since this concentration was measured in a high school library, while all other measurements were made in traditional classrooms. As a result, it can be assumed that a significant part of hexanal is emitted from the books to the indoor air.

- In Gibraltar, the highest hexanal concentration was measured in the room where a very high formaldehyde was also detected (91 µg/m^3, see next section). Therefore, it is possible and even likely that large amounts of formaldehyde and hexanal are emitted from the same source.

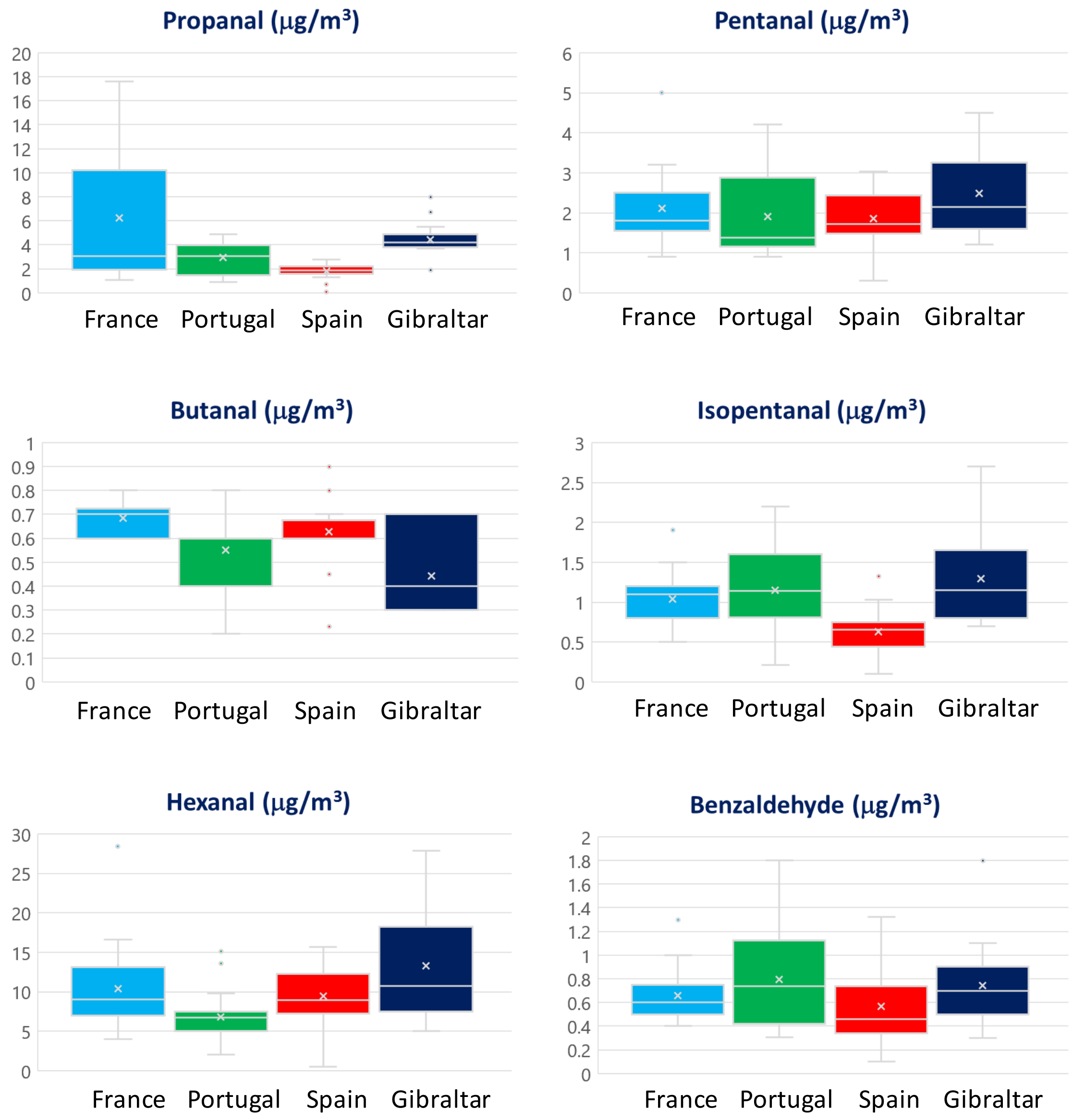


Figure 28 – Concentration distribution of pollutant without guideline by country

INDOOR AIR QUALITY RESULTS : POLLUTANTS HAVING A GUIDELINE

Figure 29 presents the number and percentage of concentrations over the guideline by pollutant and by country. First, it can be noted that any VOC and aldehyde concentration is over the guideline, except for formaldehyde. Especially, all benzene concentrations are below 2 µg/m³, which is an amazing result if considering that benzene has been demonstrated to be carcinogenic with an excess lifetime risk of leukaemia of 6 x 10^{-6} at an air concentration of 1 µg/m³. On the other hand, concentrations are over the guidelines in more than 50% of the classrooms investigated for $PM_{2.5}$, PM_{10} and CO_2, 20% of classrooms for TVOCs, and 9 % of classrooms for formaldehyde. Detailed results are presented hereafter for those contaminants. The emphasis is put on explaining high concentrations and possibly highlighting significant differences in different countries.

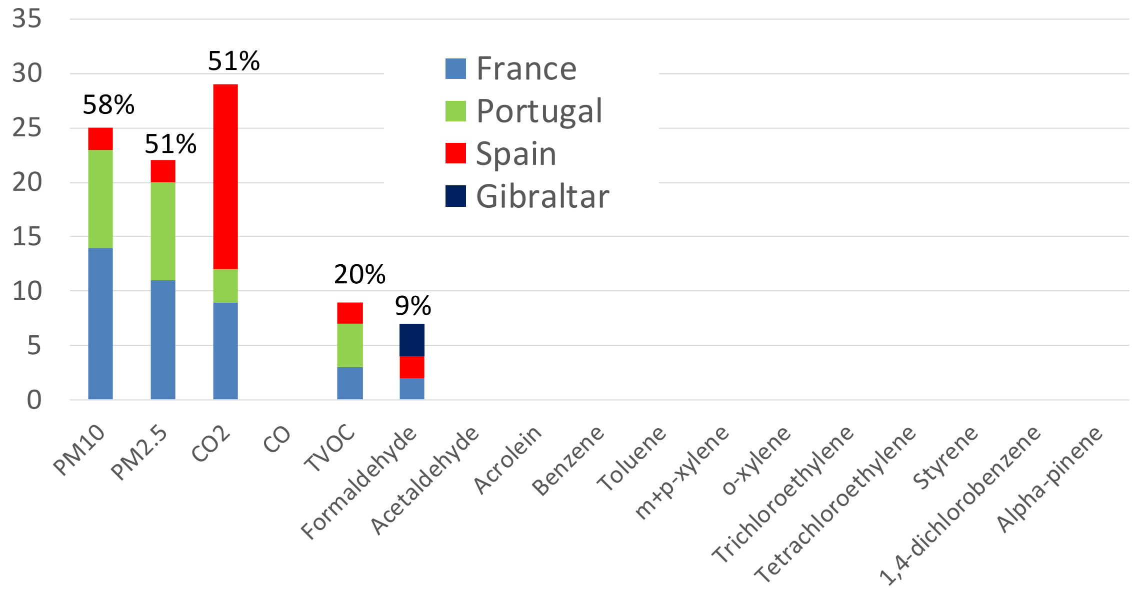


Figure 29 – Number and percentage of concentrations over guideline by pollutant and by country

Airborne particles ($PM_{2.5}$ and PM_{10})

Airborne particle concentrations were found to be lower in Spanish schools than in Portuguese and French schools (Figure 30 and Figure 31). Care must nevertheless be taken when comparing the data coming from different countries, and also measured concentrations to the guidelines.

One reason is that none of the partners has used a standard method to determine airborne particle concentrations: for all the measurements, particle counters were used to monitor particle numbers in the classrooms. These counts were then converted to mass concentrations using typical particle densities. One advantage of this method is that time series of particle numbers are very helpful to understand the fate of particles in classrooms, and then to interpret the resulting concentration levels. On the other hand, particle counts in narrow size intervals, and their conversion to mass concentrations, lead to great measurement uncertainties.

Another reason is that different instruments were used in Spain, Portugal and France. However, particles counts can be significantly different from one instrument to another. Moreover, the type of instrument used sometimes impose constraints on the location of the sampling point. Especially the distance from the floor is an important parameter since concentrations can be greatly influenced by resuspension processes when people are in the room (see below).

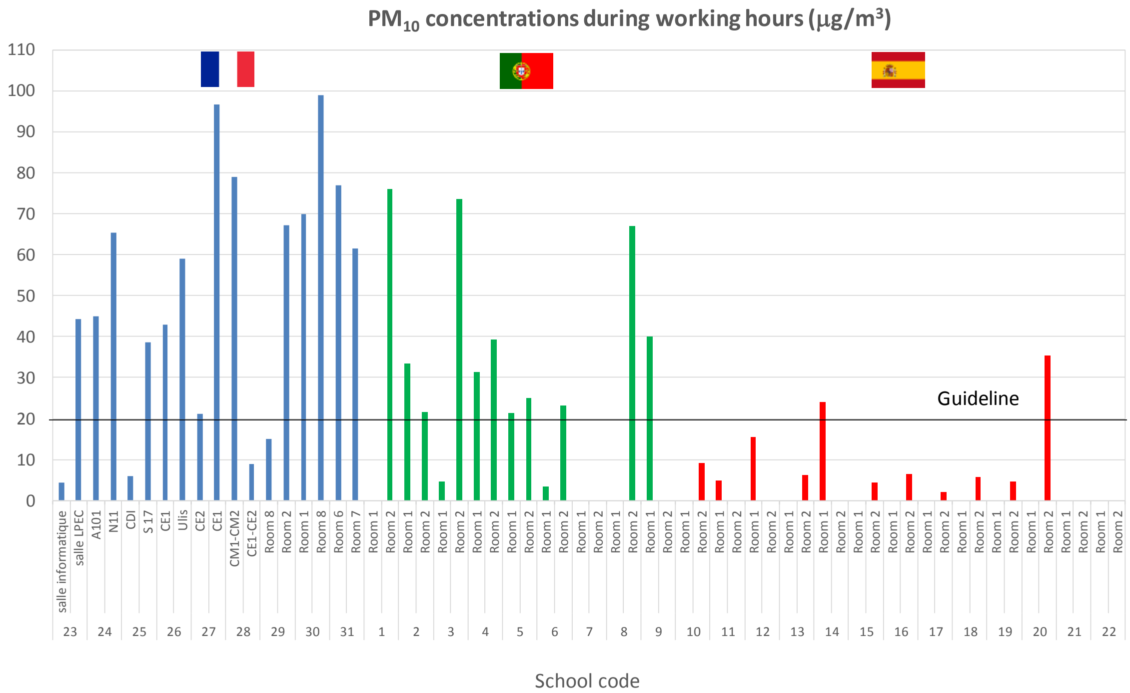


Figure 30 – PM_{10} concentrations during working hours in French, Portuguese and Spanish schools

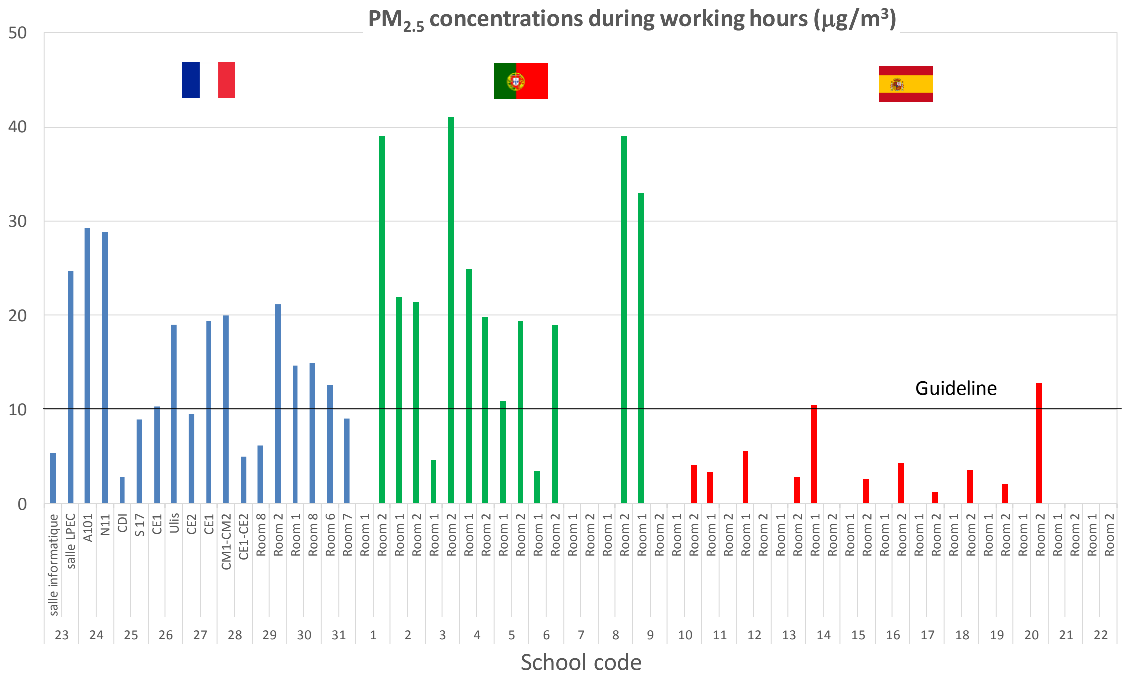


Figure 31 – $PM_{2.5}$ concentrations during working hours in French, Portuguese and Spanish schools

Despite uncertainty, many concentrations are so high that there are few doubts they are over the guideline. The time series of $PM_{2.5}$ and PM_{10} were analyzed, together with the occupancy pattern of the rooms, window openings, and outdoor concentrations (when available), as a way to determine the main factors affecting the occupants' exposure to fine and coarse airborne particles. Figure 32 is provided as a representative example, as well as an interesting case study, since 1) airborne particle concentrations heve been monitored for one full week starting from Friday afternoon, 2) the number of students varied all the days long with a maximum of 35 occupants (school 24 is a high school where teachers and students change classroom each hour or each 2-hours), 3) windows were opened from time to time, and 4) outdoor concentrations during the experimental period are also available.

PM concentrations during the week-end result from particle transports from outdoors to indoors through air infiltrations. They are significantly lower than the WHO guidelines of 10 µg/m^3 for $PM_{2.5}$ and 20 µg/m^3 for PM_{10}. On the other hand, PM_{10} concentrations tremendously increase as soon as people come in the room, with the consequence that the weekly mean concentration during the occupancy period is far above the guideline (65 µg/m^3 here). Therefore, human activity clearly appears as the major contributor to the effective emissions of coarse particles in classrooms. The sources can actually be of three types: first of all is direct shedding from the human envelop, including the release of previously deposited particles from clothing surfaces, hair or bare skin. Banghar et al (2015) estimated from measurements in a university classroom that the shedding rate can be as high as 3x10^6 part/h/person. There may also be significant contributions caused by educational activities such as plastic art works or schalk writing on a blackboard. Finally, sources can also include the resuspension of particles that had previously settled onto upward facing indoor surfaces. The parts of each type of source to the concentrations are difficult to assess, but the first and last ones are likely to be dominant in a majority of the classrooms investigated.

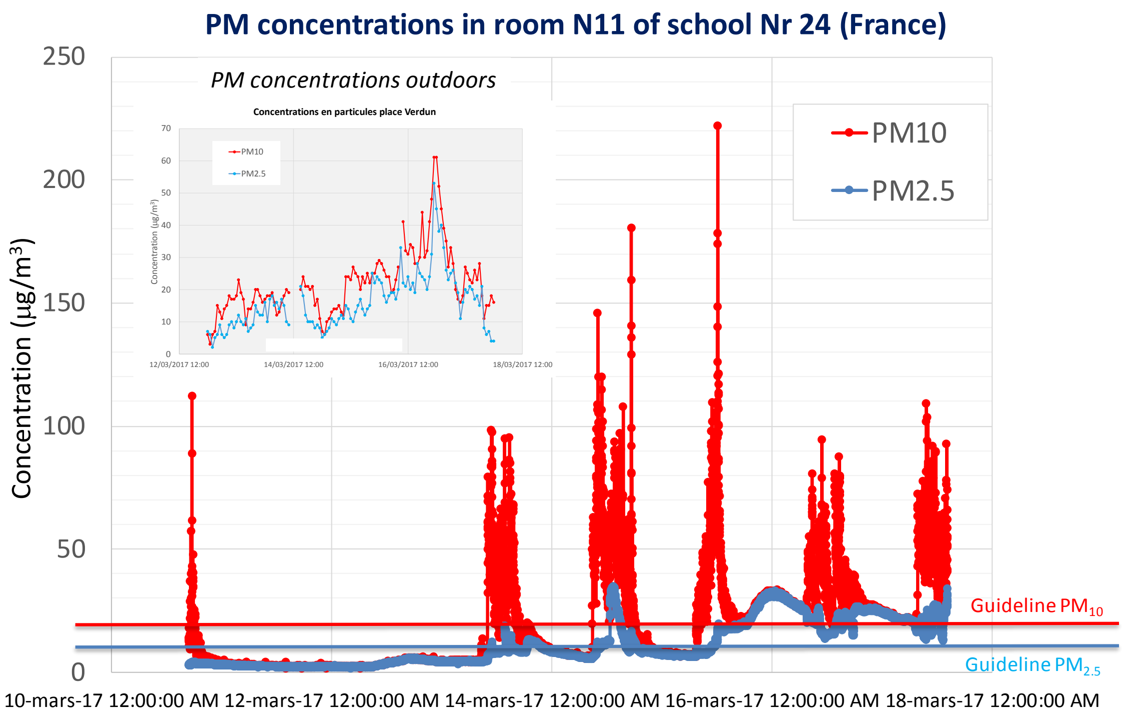


Figure 32 – Time series of PM concentrations in classroom N11 of high school 24

Occupants also impact $PM_{2.5}$ concentrations, but in a weaker way. There are actually no strong indoor emission sources of fine particles in schools. Furthermore, the deposition rate of fine particles onto indoor surfaces is lower than that of coarse particles. As a result, neither resuspension is expected to dominate $PM_{2.5}$ transports in classrooms. Finally, the main part of fine particle concentrations indoors is likely of outdoor origin, as illustrated on Figure 32: indoor $PM_{2.5}$ concentrations are a bit higher at the begining of the week than during the week-end, but they keep below or close to the WHO guideline for long term exposures. Then, an atmospheric pollution episode occurred in the middle of the week (see inner graph on Figure 32). From this time, the indoor concentrations keep over the guideline, and reach their maximum while the room is empty and the windows are closed.

Formaldehyde

Figure 33 presents the boxplots of formaldehyde concentrations by country. It shows that concentrations are close eachother, and a bit lower in Portugal than in the other SUDOE countries. Concentrations are over the guideline of 30 $\mu g/m^3$ in only three classrooms. Moreover, concentrations exceed the guideline by a very little amount in two of them. On the other hand, the concentration of 91 $\mu g/m^3$ which was measured in Room 2 of S32 is of concern. The problem is probably not a general school problem since the concentration measured in the other classroom is below the guideline, but investigations have been carried out to try to identify the emission source.

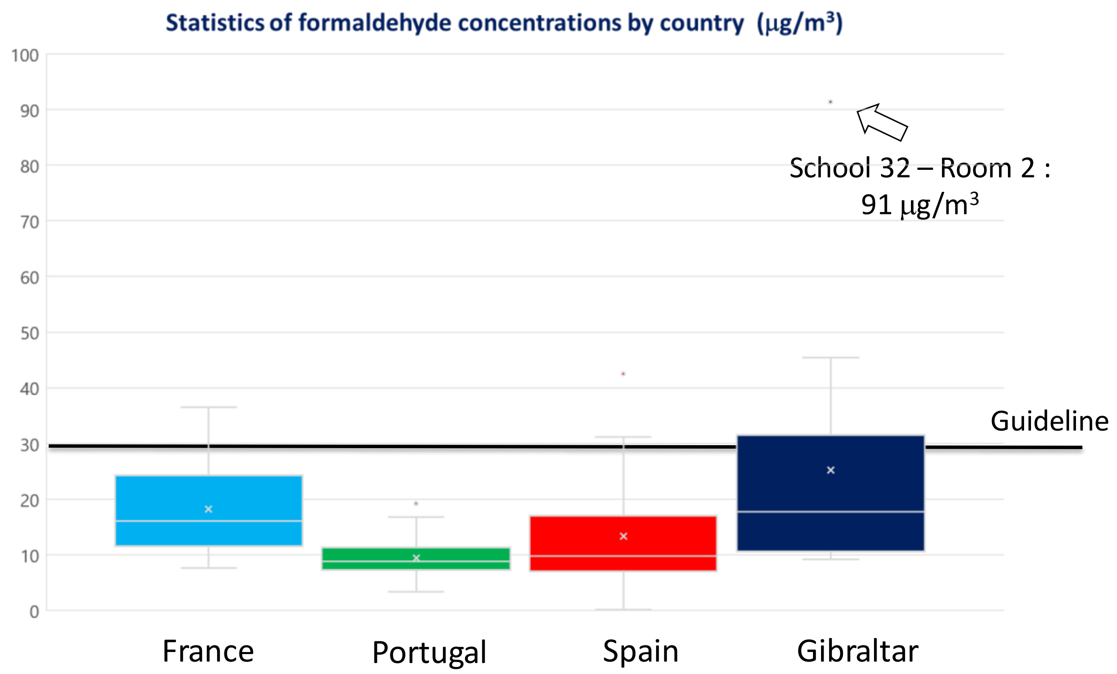


Figure 33 – Statistics of formaldehyde concentrations by country ($\mu g/m^3$)

Total Volatile Organic Compounds

Figure 34 and Figure 35 present the TVOC concentrations that were measured in French, Portuguese and Spanish schools. Unlike particles, same instruments were used in all countries, and calibrated at the beginning of the experimental campaigns. Therefore, all concentrations can be confidently compared.

Concentrations are a bit lower in Spain (median = 295 $\mu g/m^3$) than in Portugal (361 $\mu g/m^3$) and France (459 $\mu g/m^3$), on the whole. The data set also has a larger dispersion in Portugal than in the other countries, with values scattered from very low concentrations to more than 800 µg/m^3.

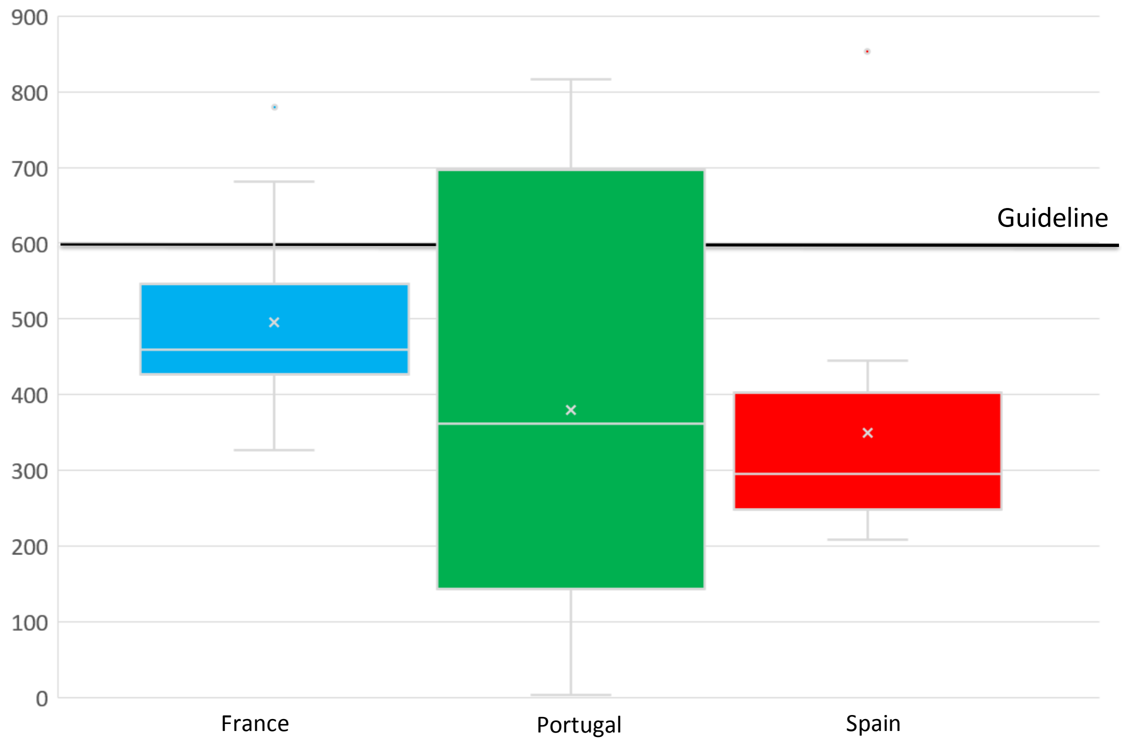


Figure 34 – Statistics of TVOC concentrations during working hours, by country (µg/m^3)

The guideline of 600 µg/m^3 is obviously not a health-based guideline since the health impact of VOCs would depend on the individual concentrations of VOCs in the mixture, which are not available. Therefore, the guideline must only be regarded as a quality target, and concentrations over 600 µg/m^3 should not be interpreted as an obvious health risk. It is nevertheless interesting to explain the large dispersion of the dataset by analyzing the time series of concentrations. Figure 36 provides a representative example of the conclusions that were drawn from these concentration profiles. As for coarse particles, TVOC concentrations peak when people are in the room, and then decay when they leave it, due to dilution by airflows. As a result, occupants clearly contribute in a significant way to VOC emissions in the indoor air, through their activities (use of marker pens, glues, plastic art products, etc.), the biogenic direct emissions (organic bioeffluents emitted from the body surface as well as VOCs contained in the exhaled air), the use of cosmetics (body lotion, fragrances, etc.), and possibly second-hand tobacco-smoke desorbed from the hair and clothes. The last assumption is all the most likely that concentration peaks during occupancy periods are higher in high school and university classrooms than in primary schools. For the case study presented in Figure 36, TVOC concentrations during the week-end steady around 520 µg/m^3, as a result of emissions by building materials and furnishings. Concentrations peaked at 1000 µg/m^3, and even 1300 µg/m^3 on tuesday when students were numerous and windows were kept closed, which shows that emissions from humans can be of the same order of magnitude as material emissions in a classroom.

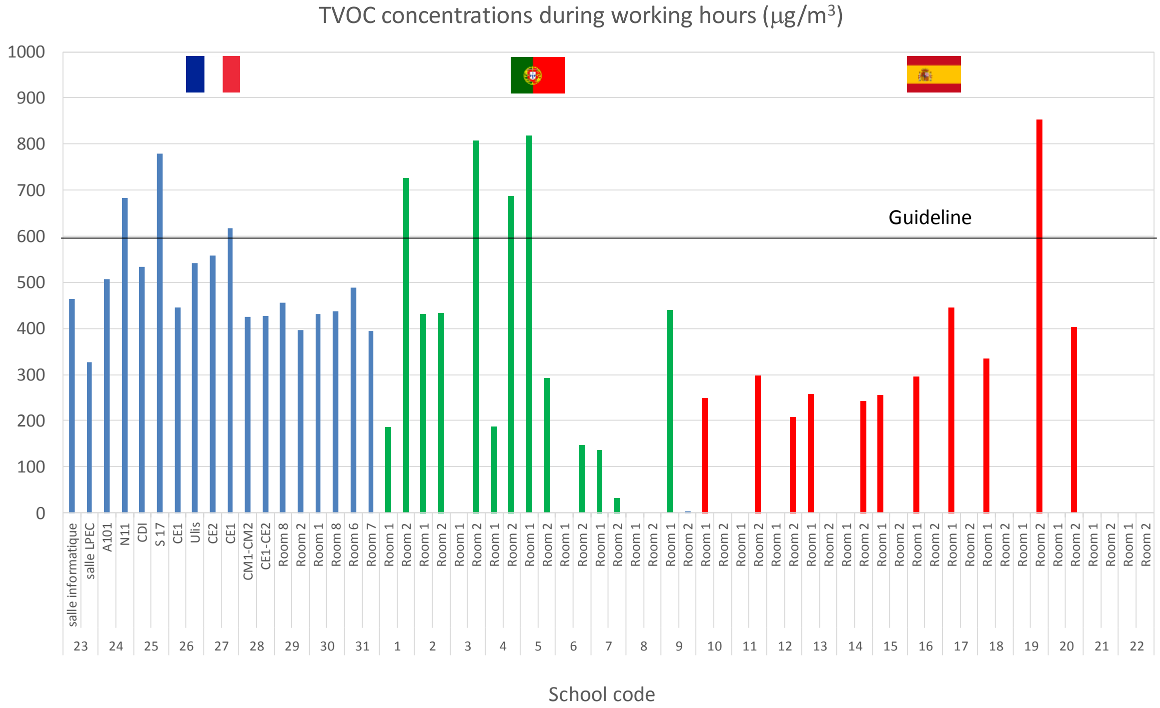


Figure 35 – TVOC concentrations in classrooms during the occupancy period (µg/m^3)

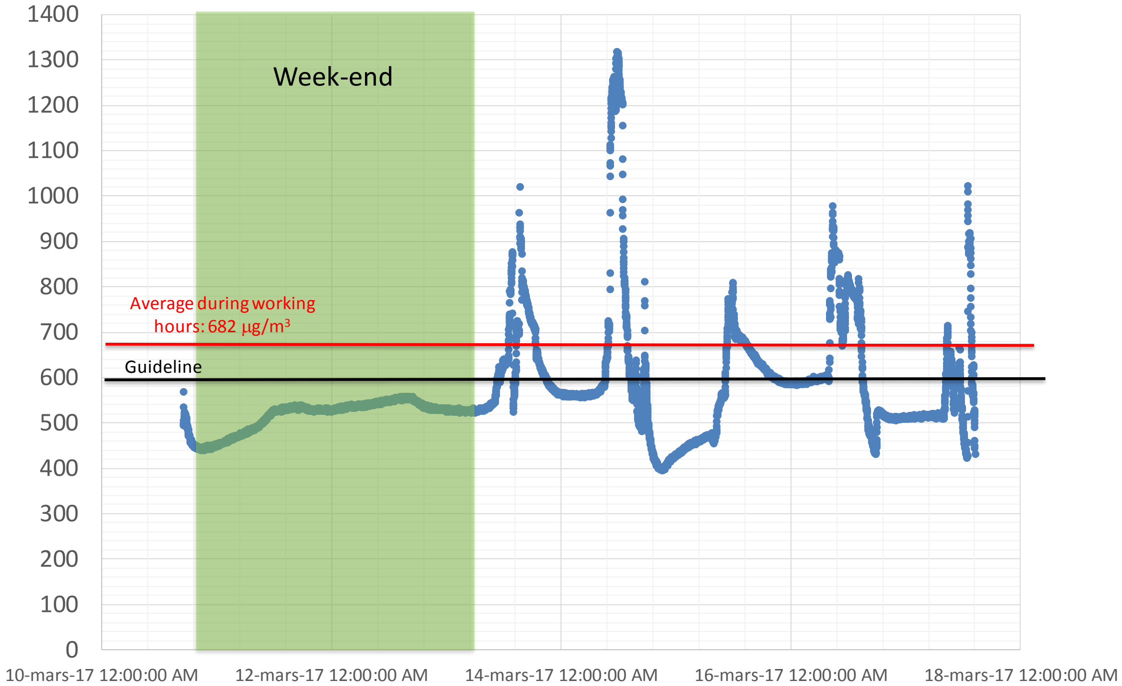


Figure 36 – Time series of TVOC concentrations in classroom N11 of high school 24

INDOOR AIR QUALITY SCORES

Figure 37 shows the computed global IAQ scores in all pilot schools. Pollutant concentrations were considered to be the same in the two classrooms when they were measured in only one of them. For the pollutants where any measurement was carried out in the school, the concentrations in the two classrooms were supposed to be below the guideline. This obviously favours a higher IAQ score for the school, especially when concentrations over the guideline could be observed for these pollutants in other schools. Consequently, the highest scores in Gibraltarian schools does not necessarily mean that the indoor air quality is better than in the other pilot schools. Generally, the minimum score is 4 over 5, which indicates that, despite some guideline exceedances, indoor air quality is quite good in all schools investigated.

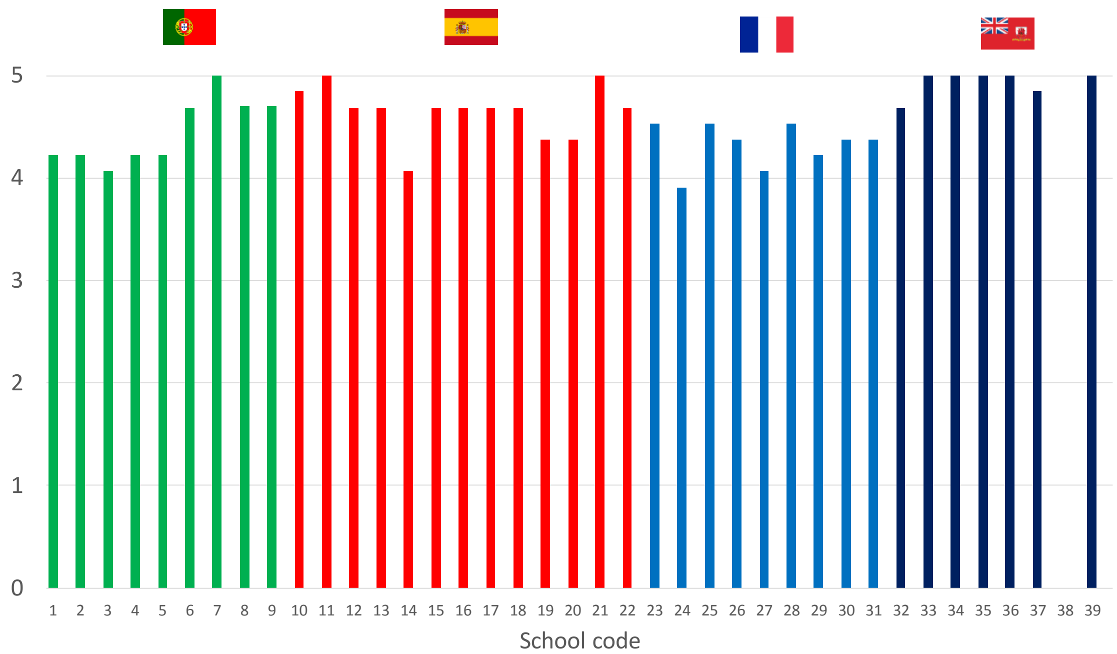


Figure 37 – IAQ scores in pilot schools

CO_2 CONCENTRATIONS AND VENTILATION SCORES

The ventilation rate of classrooms has been demonstrated to have an impact on the student's training performance. Here, the degree of air stuffiness (CO_2 concentrations) in Portuguese schools was found to be lower than in French and Spanish schools, on average, although two schools exhibit high CO_2 concentrations (outliers on Figure 38). One should nevertheless not draw definitive conclusions from these results considering the small size of the school samples on the one hand, and that measurements were carried out over a short time on the other hand. Favorable weather conditions during the tests may have promoted longest periods of window openings. In other words, the period when the measurements were carried out is not necessarily representative of common practices and mean air stuffiness in the classrooms.

As noted earlier, CO_2 concentrations are a balance between metabolic production by humans and dilution by the air change rate. Consequently, high CO_2 concentrations in a room can result from insufficient ventilation, high occupation rate, or a combination of the two. The analysis of concentrations profiles and occupancy patterns in French schools lead to the conclusion that exceedances of the guidelines were due to a malfunction of the mechanical ventilation system in one classroom (Figure 39; CO_2 concentrations should not exceed 1000 ppm if the system was working properly) , and to airtight envelopes/unsufficient window openings in the other cases. This latter situation is illustrated on Figure 40. The building has no mechanical ventilation system and its envelop is airtight. As a consequence, the air change rate due to infiltrations is low. If windows are not opened when people leave the room at the end of the afternoon, the indoor CO_2 concentrations decay so slow that they don't reach the outdoor level of 500 ppm when students are back the next morning. The week-end time is just enough to reach the baseline concentration of 500 ppm.

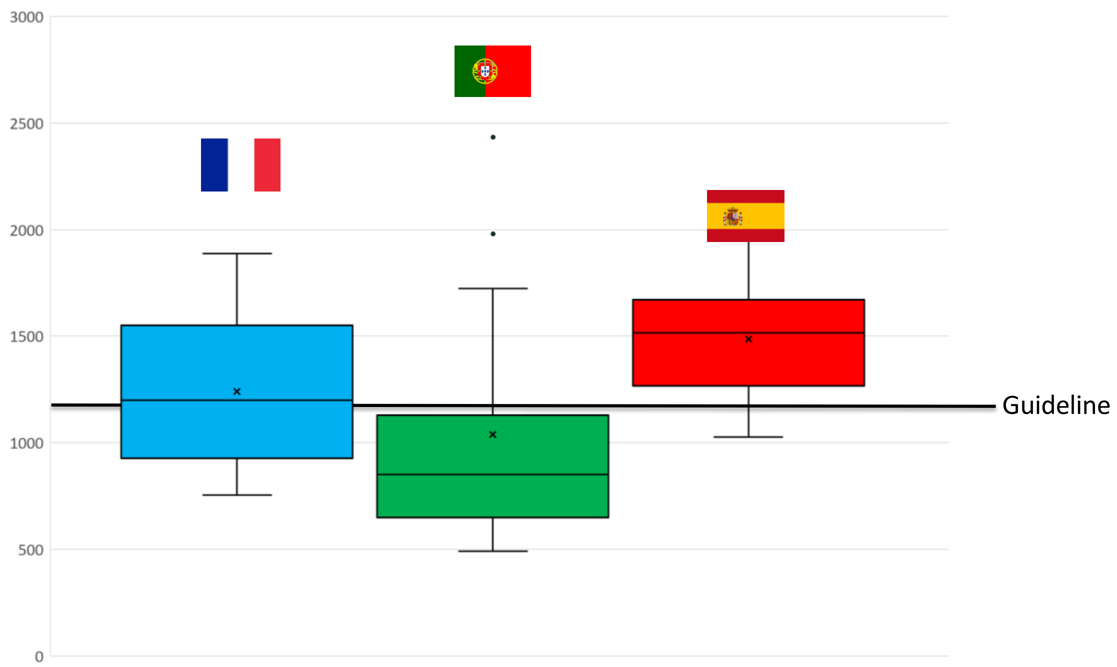


Figure 38 – Mean CO_2 concentrations during working hours by country

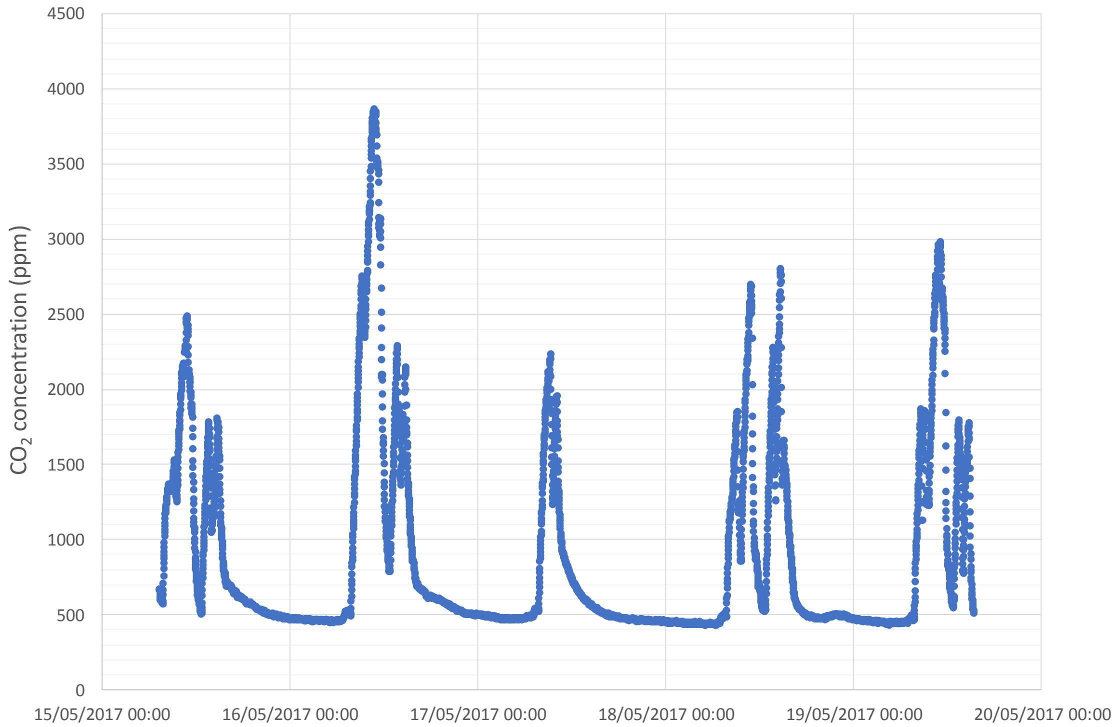


Figure 39 – Time series of CO_2 concentrations in room 6 of school 31

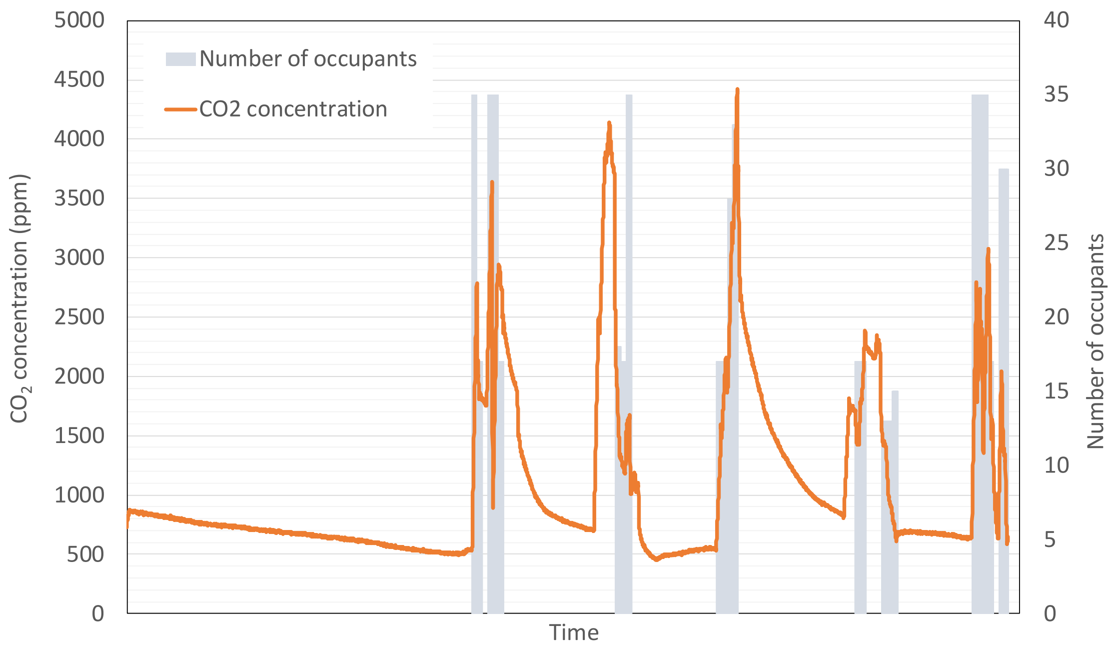


Figure 40 – Time series of CO_2 concentrations in room N11 of high school 24

CO_2 mean concentrations are over the guideline of 1250 ppm in almost all Spanish schools. Their CO_2 concentration profiles and occupancy patterns have not been analyzed in details yet, but the main reason might be high occupation rates. Indeed, unsufficient air renewal would also result in high concentrations of pollutants of indoor origin, such as TVOC, formaldehyde and other specified VOCs/aldehydes, which is obviously not the case.

Figure 41 shows the ventilation scores for the two classrooms investigated in each pilot school. These scores are in agreement with the mean CO_2 concentrations presented on Figure 38. It is overall interesting to note that the scores vary in a wide range, and they can be significantly different in the classrooms of a same school, while the building caracteristics and operation parameters are similar. This highlights the potential of efficient ventilation systems and window openings to decrease air stuffiness, and subsequently improve indoor air quality in schools.

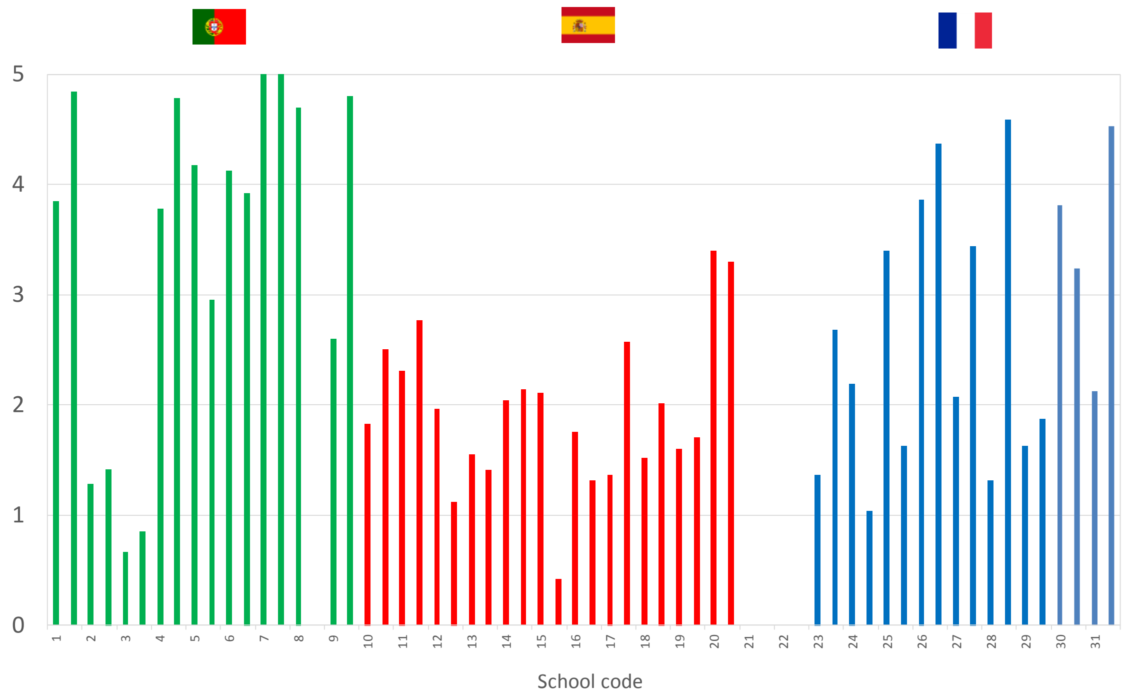


Figure 41 – Ventilation scores in the two classrooms of the pilot schools

FINAL REMARKS

The audits performed in the 39 ClimACT schools gave a first status of these schools performance in what concerns the environmental and energy sectors. According to the obtained results it is possible to state that, in general, schools have a large margin for improvement.

Per sector, the main issues observed are:

- **Transports:** Should be prioritize the insfrastructures of bicycle parking spaces and electric cars charching places, accompanied by a correct awareness of the school community to change behaviours and to opt for the best transport to perform their daily commuting home-school.
- **Green procurement**: It is extremely important to performe a good awareness in the school's management responsibles, and also in the rest of the school community, allowing the realization of green choices by schools.
- **Green spaces**: A good management of the green spaces is needed, mainly in what concerns the increase of the green spaces and the green species there included. The selection of the trees should be based in to facts: 1)the sequestration factor, and 2) if it is an autochthonous specie.

- **Energy:** Energy audits showed that a huge improvement of this sector is needed in order to reduce school's energy consumption. To improve their performance schools should improve the management of energy and the school community should be alert to behaviors that increase the energy consumption. Other measures that require financial resources have also a great potential but the low budget of schools is a barrier for the application of this type of measures.
- **Water:** The audits in the water sector revealed an unbalanced sector, as some schools have water saving measures in place, while others have higher consumption of water. However, the scores obtain did not reflect the observations. The problem with the water sector is the difficulty in normalizing the results due to the differences in green spaces. Despite the results it is easy to point out that most schools can reduce their water consumption if they start using water savings measures, especially in the irrigation systems.
- **Waste:** The results show that schools can easily improve the scores if they start to recycle a larger amount of the waste produced, which can be done by engaging the students in the importance of recycling and increase the amount of recycling bins around the schools.
- **Indoor air quality:** Results revealed low concentrations of chemical compounds in a large majority of pilot schools, which is obviously a good point. The analysis of the time-series of PM2.5, PM10, and TVOC concentrations showed that they mainly originate from human bodies and occupancy (which is of course also the case for CO_2). Consequently, promoting higher ventilation rates, either through longest periods when windows are open or by the implementation of mechanical ventilation systems, seems to be a key point for the improvement of IAQ and the reduction of the air stuffiness in schools. This may nevertheless go against energy savings, which highlights that health issues shall be addressed when designing and assessing solutions to improve the environmental performance of schools.

As a general remark, these schools can improve their performance mainly changing behaviours, as a consequence of a good awareness, and by changing equipments/improving infrastructures.