LIFE my building is green

LIFE17 CCA/EN/000088

Application of Nature-Based Solutions for local adaptation of educational and social buildings to Climate Change

Action: C2.

Deliverable: Action plans for the implementation of induced natural ventilation and seasonal shading formulas.

Date: 12/31/2020

LIFE my building is green - LIFE17 ENV/ES/000088

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Data Project

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SUMMARY EN ESPAÑOL

This deliverable includes the studies carried out by the Project in order to define ventilation protocols in classrooms to maintain appropriate thermal comfort inside.

First, the analysis of climatic data from the study areas is presented and how bioclimatic strategies can make possible to adapt buildings for achieving indoor thermo-hygrometric conditions without using active air conditioning systems. In this sense, the main results of the study of applying this methodology to the three schools that participate in LIFE myBUILDINGisGREEN are presented.

Next, a calculation methodology is introduced to define the necessary openings looking for adequate ventilation in different conditions. In addition, different configurations that can be followed depending on the layout of the openings in the classroom are presented.

In an independent section, a laboratory study is presented that assesses the impact of introducing vegetation (for indoor environments or in the air inlet area to the building) to reduce the air temperature (in high temperature situations) depending on the type of vegetation and the irrigation conditions.

Finally, generic ventilation protocols are established for schools seeking to maintain adequate thermo-hygrometric conditions inside. This section presents the tool that is being developed to make the diagnosis in each classroom, support in the calculation of the openings and times necessary for air renewals and to offer recommendations among the solutions that the Project is working on. Furthermore, with this tool, suitable monitoring schemes can be set up to assess their impact.

2. SUMMARY IN SPANISH

This deliverable includes the studies carried out by the Project in order to define ventilation protocols in the classrooms suitable for maintaining thermal comfort inside them.

First, the analysis of climatic data from the study areas is presented and how bioclimatic strategies can allow to adapt buildings to achieve thermo-hygrometric conditions inside for as long as possible without the need to use active air conditioning systems. In this sense, the main results of the study of applying this methodology to the three schools participating in LIFE myBUILDINGisGREEN are presented.

A calculation methodology is then introduced to define the required openings for adequate ventilation under different conditions. In addition, the different configurations that can be followed depending on the arrangement of the openings in the classroom are presented.

In a separate section, a laboratory study is presented that assesses the impact of introducing vegetation solutions (indoors or in the air inlet area of the building) to reduce air temperature (in high temperature situations) depending on the type of vegetation and irrigation conditions.

Finally, generic ventilation protocols are established for schools in order to maintain adequate thermo-hygrometric conditions inside. In this section we present the tool we are working on to perform the diagnosis in each classroom, to support in the calculation of openings and times needed for air renewals and to offer recommendations among the solutions that the Project is working on. In addition, this tool can be used to set up appropriate monitoring schemes to evaluate its impact.

3. RESUMO EM PORTUGUÊS

This plot includes the studies carried out by the Project in order to define ventilation protocols in the appropriate classrooms to maintain the thermal comfort inside.

Firstly, it presents the analysis of the climatic data of the study areas and how bioclimatic strategies can allow buildings to adapt to reach thermostatic conditions indoors for as long as possible without the need to use active air conditioning systems.

In this sense, the main results of the study of application of this methodology to the three schools participating in LIFE myBUILDINGisGREEN are presented, followed by a calculation methodology to define the necessary openings for adequate ventilation in different conditions.

In addition, the different configurations that can be followed depending on the opening of the openings in the classroom are presented. In a separate section, a laboratory study is presented that evaluates the impact of the introduction of vegetation solutions (for interiors or in the air inlet area of the building) to reduce the air temperature (in high temperature situations) depending on the type of vegetation and irrigation conditions.Finally, generic ventilation protocols are established for schools that seek to maintain adequate thermo-hygrometric and hygrometric conditions in their interior.

This section presents the tool we are working on to make the diagnosis in each classroom, to support the calculation of the openings and schedules required for aerial renovations and to offer recommendations among the solutions the Project is working on. In addition, with this tool you can set up adequate monitoring schemes to evaluate its impact.

4. INTRODUCTION

Most people are aware of the harm caused by outdoor air pollution. This pollution is often seen and smelled, and people with respiratory problems suffer significantly from it. However, indoor air pollution in buildings often has an even greater effect on people's health. The WHO[1] , EU[2] and the EPA[3] have studied the subject and have reported data such as that the population spends on average more than 80% of its time indoors or that indoor pollution levels are 10 to 1000 times higher in some common pollutants. On the other hand, they also attribute the premature death of 4 million people per year or more than 50% of deaths due to pneumonia in children under 5 years of age (associated to particles inhaled indoors).

An example of this has been seen in the COVID-19 pandemic we have suffered. In the case of the environmental quality of schools, this plays an important role in the health and academic performance of children, although to date it has not been given the importance it deserves. Children spend much of their time in schools and are much more likely than adults to be adversely affected by indoor air pollution. They breathe a greater volume of air relative to their body weight and this leads to a greater load of pollutants accumulating in their bodies. Scientific studies show that poor indoor air quality leads to health problems such as asthma, allergies, as well as lack of attention and care.

In respiratory physiology, an important parameter is the expired volume per minute because of its relationship to blood levels of carbon dioxide. A resting volume per minute in humans is approximately 5-8 liters. However, when we are talking about children we have to take into account that their metabolic rate generates higher oxygen demands, higher respiratory rates, shorter breathing times and less optimized thermal control than adults. All this, and a few other factors, means that air quality and thermo-hygrometric conditions affect them more than adults.

Likewise, teachers and other adult support staff present in schools also suffer from the problems that may arise and it will be especially important for people who may have certain previous pathologies. For both children and adults, poor air quality can cause absences with the consequent individual and collective damage.

In Spain, the RITE (Regulation of Thermal Installations in Buildings) since 2007 makes it mandatory for new building projects to have mechanical ventilation systems in the case of schools. There are many studies that show that the low quality of indoor air[4] (due to biological agents, different

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[1] https://www.who.int/es/news-room/fact-sheets/detail/household-air-pollution-and-health
[2] https://ec.europa.eu/health/scientific_committees/opinions_layman/en/indoor-air-pollution/index.htm
[3] EPA-Environment Protection Agency. https://www.epa.gov/indoor-air-quality-iaq
[4] https://www.epa.gov/iaq-schools / de Gennaro, G., Dambruoso, P.R., Loiotile, A.D. et al. Indoor air quality in schools. Environ Chem Lett 12, 467-482 (2014). https://doi.org/10.1007/s10311-014-0470-6 / Madureira, J., Paciência, I., Rufo, et al. Indoor air quality in schools and its relationship with children's respiratory symptoms. Atmospheric Environment Volume 118, October 2015, Pages 145-156. / Stabile, L., Dell'Isola, M., The effect of

Volatile Organic Compounds, particulate matter or even outdoor air pollutants such as nitrogen oxides or CO) affects children's cognitive development.

Likewise, in Spain, the CTE (Technical Building Code) makes demands on buildings in relation to the basic safety and habitability requirements established in the basic document that sets the general design conditions for ventilation systems "DB HS 3 Indoor air quality[5] ". The DB establishes that buildings must have a ventilation system (hybrid or mechanical) so that air circulates from dry rooms to wet rooms, thanks to the provision of **intake openings** that communicate the room with the outside, and **exhaust openings** in other rooms such as toilets. The partitions separating these rooms will have **openings** that allow air circulation.

The objective is to ensure adequate ventilation in all rooms of the building, so as to provide a sufficient **flow of** outside air and ensure the extraction and expulsion of air fouled by pollutants that are produced on a regular basis during normal use.

The **minimum ventilation flow rate** required by the CTE DB HS 3 for each room of the dwelling is as follows:

Intake flow rates:

- 5 l/s (18 m^3 /h) per occupant per classroom.
- 3 l/s (10.88 m^3 /h) per occupant in living and dining rooms.

Extraction flow rates:

- 15 l/s (54 m^3 /h) in toilets and bathrooms.
- 2 l/s (7.2 m^3 /h) per m^2 useful in kitchens.
- 0.7 l/s (2.52 m^3 /h) per useful m^2 in storage rooms and common areas.
- 10 l/s (36 m^3 /h) per useful m^2 in premises reserved for waste storage.

On the other hand, the Spanish National Institute for Safety and Hygiene at Work, in compliance with Royal Decree 485/1997, which regulates the minimum health and safety provisions in workplaces, sets a maximum temperature of 27ºC for office or sedentary work. In Portugal, the reference comfort temperature is 20ºC for the heating period and a temperature of 25ºC for the cooling period, with a humidity of 50% (Decree-Law no. 80/2006).

The above is only an indication that school facilities are in need of interventions to bring them up to the minimum standards being

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Natural ventilation strategy on indoor air quality in schools. Science of The Total Environment Volume 595, 1 October 2017, Pages 894-902.

[5] https://www.codigotecnico.org/pdf/Documentos/HS/DBHS.pdf

currently required in other areas. Most of these buildings do not meet these criteria because they were built before they were established.

As mentioned above, there are many publications that echo the conditions inside the classrooms and show that in many occasions the quality levels would not be the most adequate. In LIFE myBUILDINGisGREEN this fact has been evaluated with the measurements of temperature, humidity and CO concentration sensors$_2$ installed in the classrooms. As an example, some records taken during a hot week during September 2019 are shown.

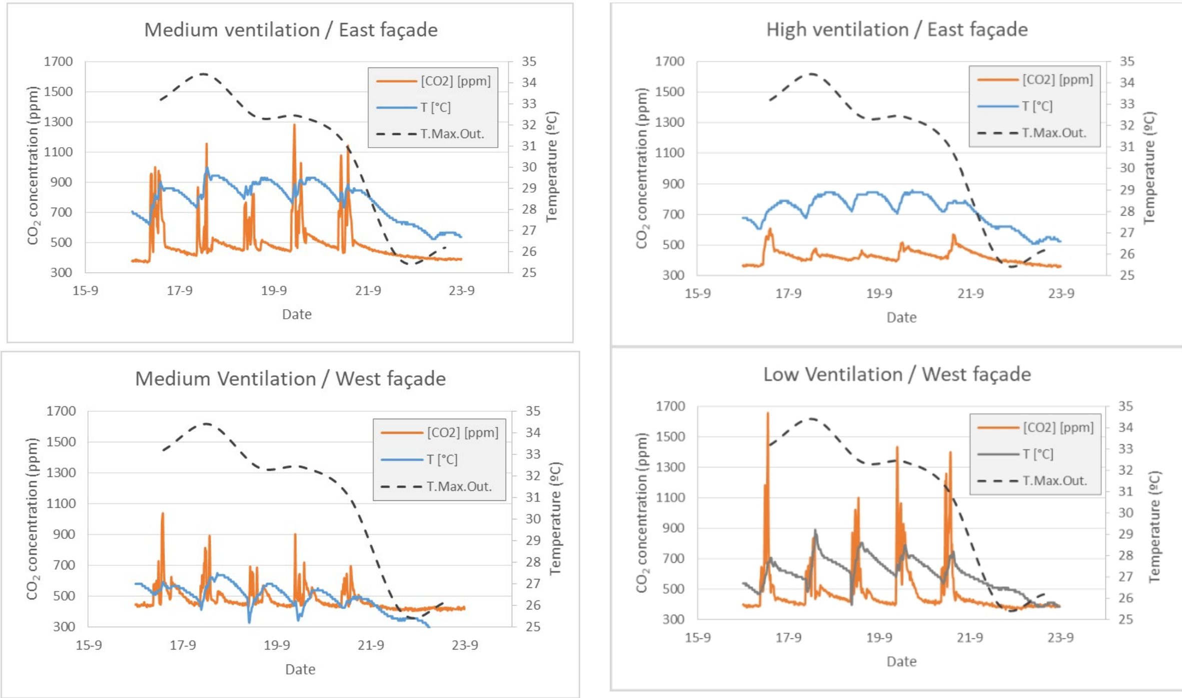


Figure 1. Humidity, temperature and CO concentration records$_2$ in some classrooms of CEIP Gabriela Mistral in Solana de los Barros (Badajoz, Spain).

As can be seen in Figure 1, the temperature profiles of the classrooms are quite different depending on the orientation. Classrooms with facades facing east have higher temperatures than those on the west facade, and consistently exceed 27ºC, a value that could be marked as a maximum of thermal comfort. In this particular school, the west façade has a row of trees less than 5 meters from the façade that shades it during the hours of maximum sunshine in the afternoon. The outdoor temperature profile (dashed line) has been included in the graphs for reference. This is a situation that can be repeated in schools during the hottest periods that coincide with the school year. These periods will be more or less extensive mainly due to the latitude where the schools are located, the further south the longer (for the northern hemisphere), but in central areas of the Iberian Peninsula they can occur for many weeks between May and October.

Likewise, and also as an example, *Figure 2* shows the profile of temperature records during the months of May to September of the school year. Likewise, a dotted line indicates the 27ºC temperature to highlight the days that exceeded it. In addition, the % of school hours exceeding this value, which is considered the maximum, is shown at the top.

Figure 2. Representation of the temperatures recorded inside one of the classrooms of CEIP Gabriela Mistral in Solana de los Barros (Badajoz) during 2019.

On the other hand, and returning to Figure 1, in relation to the concentration of CO_2 , which would indicate the ventilation conditions inside the classrooms, it can be seen how it is very variable among the different classrooms. After discussing it at school, it was found that the profiles responded to the behavior of the teachers: the teachers who were more sensitive to ventilating the classrooms kept the windows open for as long as possible, while those who were not so aware and gave more importance to other factors, such as noise, kept them closed for longer and the CO concentrations$_2$ were significantly higher. Also, analyzing the data, it is found that when there are lower concentrations of CO_2 , more ventilation, the temperature inside the classroom is also reduced as a result of introducing outside air, during the period in which this is appropriate. In principle, the assumption is made that a high concentration of CO_2 indicates poor indoor air renewal and could also be associated with a high concentration of compounds, particulate matter or biological agents.

These behaviors have been modified with the protocols indicated for return to the classroom after confinement due to COVID-19. It has been found that ventilation has increased in relation to the previous year but there are still options for improvement. These results will be presented in the results of action C3, which is in charge of monitoring the impact of the Project's actions.

In general, humidity values inside the classrooms remain between 40 and 60% throughout the year. Therefore, they would remain within the required recommendations. There are also occasional moments with maximum peak values between 70 and 80% due to low temperatures and minimum peak values between 20 and 30%, but they are not significant. In principle, the high density of people in the classrooms generates high humidity levels. Therefore, it is believed that it would not be necessary to take into account relative humidity as one of the parameters on which to intervene unless specific problems are detected in a school, due to values higher or lower than those recommended. Environments with humidities both above and below the recommendations would have to be studied individually and the most suitable plants, substrates and plant container materials would have to be selected.

In the current context in which the COVID-19 pandemic affects everything, when thinking about the opening or closing of educational schools, all the associated risks must be taken into account, both those of face-to-face and *online* education. The risks associated with not opening may be reduced physical activity of minors, reduced socialization and poorer nutrition, and that more situations of abuse, exploitation and violence may occur. On the other hand, there is the risk of spreading the virus since they are closed environments, with a high density of people, a lot of social contact and in which sometimes there is also a canteen service. This means that attendance requires the implementation of measures such as masks, social distance, hygiene and, very importantly, indoor air renewal.

Evidence shows that the risks of both infection and serious cases of the disease are much lower in children than in adults and that they have been found to have lower transmission rates. However, as the group of adults working in schools must not be forgotten, the above recommendations must continue to be strictly observed.

Considering the benefits and the associated risks, the opening of schools is believed to be a good action. However, it must be accompanied by measures to ensure compliance with recommendations to reduce the risk of virus transmission. On the other hand, while some of these may be relaxed when the pandemic is at controlled levels, others may be solutions that can be maintained to improve indoor air quality in classrooms and also improve indoor thermal comfort.

The following are the studies carried out in LIFE myBUILDINGisGREEN to try to implement natural ventilation measures in schools in order to improve thermal comfort, but also to improve indoor air quality. The recommendations and protocols proposed are not limited to the current period, but would be valid in the future because there are many other factors to be improved beyond reducing the risk of COVID-19 virus transmission.

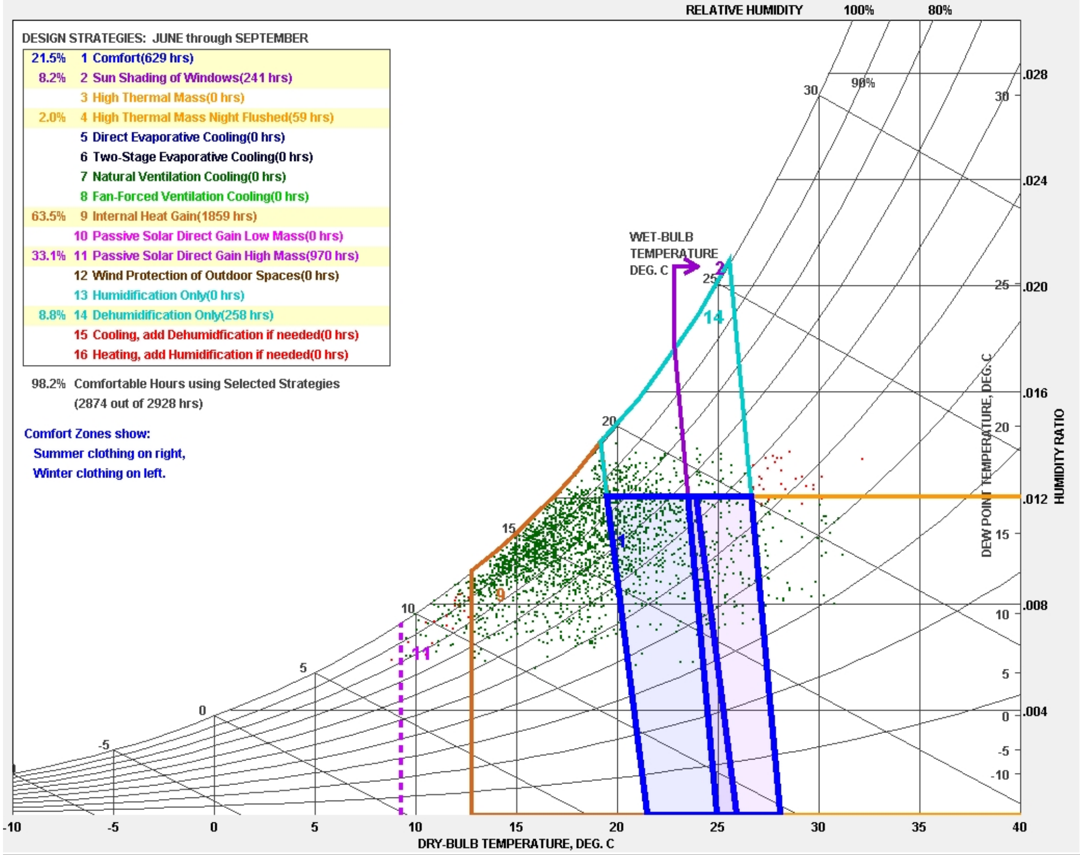
The solutions arise from the analysis of existing bioclimatic strategies and their combination are natural solutions that can facilitate the adaptation of buildings to climate change in relation to the challenge of maintaining thermal comfort and improving indoor air quality while following sustainability criteria for both implementation and use.

5. BIOCLIMATIC STRATEGIES: NATURAL VENTILATION

The strategies to be implemented in the project are aimed, as mentioned above, at improving thermal comfort inside the building without requiring an increase in the energy demand for cooling. However, the necessary strategies for the whole year are analyzed in order not to introduce improvements for summer that would mean a worsening of the building's energy performance during winter.

To support the selection of the most appropriate strategies for each of the locations, psychrometric abacuses have been used to plot hourly climatic data for human comfort, specifically dry temperature (sensible heat) and relative and absolute humidity.

The same graph shows the comfort zones defined for summer and winter based on temperature and humidity parameters. The plotted time points outside these zones indicate periods of discomfort. Depending on their location in the areas of the graphic, it is possible to establish bioclimatic strategies that allow the approach to comfort zones. These strategies are defined in Givoni's studies[6] for these abacuses.



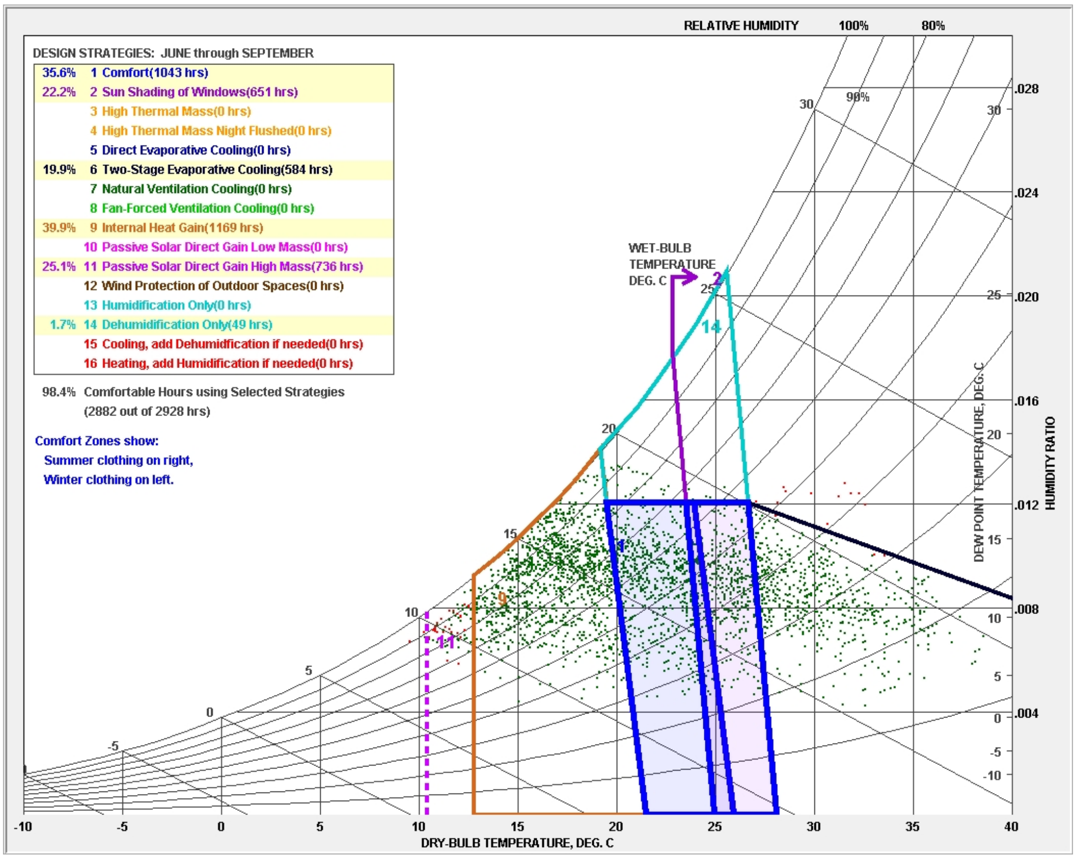
Psychrometric diagram with incorporation of the most appropriate passive improvement measures during the summer at the Porto location (UCLA, 2008).

For this study, the *Climate Consultant 6.1* (UCLA, 2008) software tool ([7]) was used to facilitate the input of climate data into the abacuses. The results are presented for the 3 locations.

According to the analysis of the psychrometric diagram, the most suitable passive measures for the reduction of cooling demand during the months of June to September in the temperate and humid climate of Porto are the following:

- Shading of openings to prevent interior overheating
- Cross ventilation
- Internal profit control
- Exploitation of thermal inertia
- Dehumidification

[6] Baruch Givoni 1992. Comfort, climate analysis and building design guidelines. Energy and Buildings, Volume 18, Issue 1, 1992, Pages 11-23, https://doi.org/10.1016/0378-7788(92)90047-K.
[7] http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php



Psychrometric diagram incorporating the optimal passive enhancement measures during the summer for the Évora location (UCLA, 2008).

In the case of EVORA, the recommended measures would be:

- Shading of openings and outdoor spaces during summertime
- Cross ventilation
- Evaporative cooling systems
- Management of internal loads
- Light colors and reflective coating

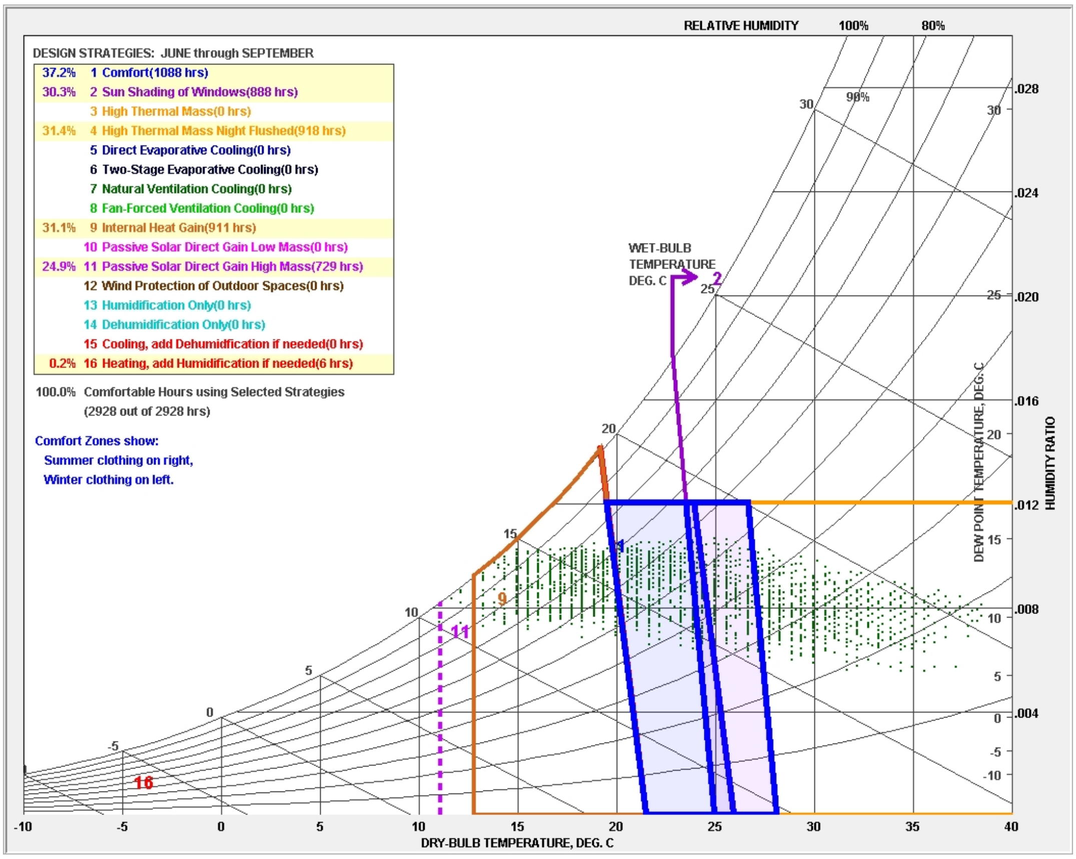


Figure 5 Psychrometric diagram incorporating the optimal passive enhancement measures during the summer for the Badajoz location (UCLA, 2008).

In the case of Badajoz, the following recommendations are obtained:

- Reflective flat cover
- Gap shading (maximum shading in summer and minimum shading in winter)
- Evaporative cooling systems
- Exploitation of thermal inertia
- Night ventilation
- Management of internal loads
- Use of ceiling fans

As can be seen, ventilation strategies appear for all three locations, although with greater weight in those of warm climates such as Badajoz and Évora. In addition, in Badajoz, night ventilation (*free cooling*) is proposed in order to reduce the temperatures reached during the day and accumulated in the thermal masses.

For the specific study of the impacts of the application of bioclimatic strategies in buildings, energy studies have been carried out using the *Design Builder* software *(v.6)*[8] .

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[8] https://www.designbuilder-lat.com/

Detailed results can be read in the article[9] : *Selection of Nature-Based Solutions to improve comfort in schools during heat waves.* G. Gómez, B. Frutos, C. Alonso, F. Martín- Consuegra, I. Oteiza, F. de Frutos, M. Castellote, J. Muñoz, S. Torre, J. Fermoso, T. Torres, M.A. Antón, T. Batista, N. Morais. In publication status: *International Scientific Journals by WIT Press.*

As a summary, some of the results and recommended solutions have been extracted for each of the case studies analyzed. The simulated solutions for each school involve cumulative bioclimatic strategies in which ventilation appears at the end of them.

CEIP Gabriela Mistral. Solana de los Barros (Badajoz). Spain.

- S0. Solution in current status
- S1: S0 + Facade shading solution.
- S2: S1 + Shading solution using exterior trees.
- S3: S2 + Green roof installation.
- **S4: S3 + Incorporation of ventilation.**

Escola Básica Horta das Figueiras. Évora. Portugal.

- S0. Solution in current status
- S1: S0 + Shading solution using exterior trees.
- S2: S1 + Green roof installation.
- S3: S2 + Installation of wiring with vegetation on east facades.
- S4: S3 + Installation of green façade in west orientation
- **S5: S4 + Incorporation of ventilation.**

Escola EB1 Mello Falcão. Porto. Portugal.

- S0. Solution in current status
- S1: S0 + Shading solution using exterior trees.
- S2.1: S1 + Green roof installation.
- S2.2: S2.1 + Solar roof.

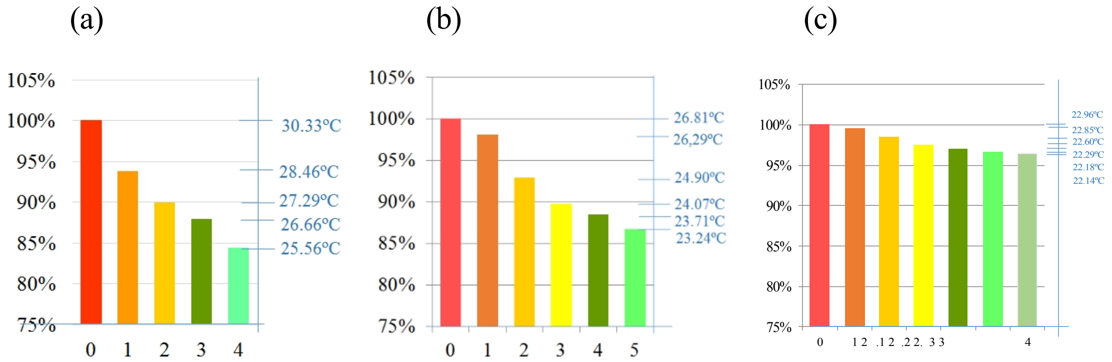
[9] https://digital.csic.es/handle/10261/231004

- S2.3.: S2.2 + Pitched roof treatment

- S3: S2.3 + Installation of wiring with vegetation on east facades.

- S4: S3 + Incorporation of ventilation.

A summary of the indoor temperature reduction results after simulation of the proposed strategies is shown in Figure 6.



Reduction percentages and temperatures reached after simulation of the strategies.
Cases of Badajoz (a), Évora (b), Porto (c).

It can be seen that the reductions attributed to ventilation are important for the cases of Évora (S4) and Badajoz (S5) due to the "*free* cooling" effect[10] caused by night ventilation. Figure 7 shows the simulation results broken down for the different months with higher temperatures.

[10] Night ventilation. https://en.wikipedia.org/wiki/Free_cooling

BADAJOZ

Month	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	%	° C less	%	° C less	%	° C less	%	° C less
May	**94,17%**	1,51	**89,38%**	2,76	**87,72%**	3,19	**87,60%**	3,22
June	**93,77%**	1,87	**90,03%**	2,99	**87,99%**	3,60	**85,32%**	4,41
July	**93,10%**	2,27	**89,10%**	3,59	**86,76%**	4,36	**81,48%**	6,10
August	**93,41%**	2,17	**89,51%**	3,45	**87,12%**	4,23	**81,65%**	6,03
September	**94,78%**	1,56	**91,84%**	2,44	**90,04%**	2,98	**86,24%**	4,11

EVORA

Month	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	%	° C less	%	° C less	%	° C less	%	° C less	%	° C less
May	**98,00%**	0,48	**92,11%**	1,90	**88,54%**	2,77	**87,81%**	2,95	**84,87%**	3,65
June	**98,26%**	0,45	**92,74%**	1,89	**89,33%**	2,78	**88,01%**	3,12	**86,17%**	3,60
July	**98,69%**	0,37	**92,79%**	2,04	**89,26%**	3,04	**87,24%**	3,61	**86,60%**	3,79
August	**98,35%**	0,46	**93,44%**	1,82	**90,44%**	2,66	**88,62%**	3,16	**88,02%**	3,33
September	**97,06%**	0,82	**93,26%**	1,87	**91,12%**	2,46	**90,49%**	2,64	**87,46%**	3,48

PORTO

Month	Scenario 1		Scenario 2.1		Scenario 2.2		Scenario 2.3		Scenario 3		Scenario 4	
	%	° C less	%	° C less	%	° C less	%	° C less	%	° C less	%	° C less
May	**99,49%**	0,10	**98,53%**	0,30	**97,71%**	0,47	**97,31%**	0,55	**96,89%**	0,64	**96,89%**	0,64
June	**99,55%**	0,11	**98,22%**	0,43	**97,04%**	0,72	**96,44%**	0,86	**96,16%**	0,93	**95,72%**	1,03
July	**99,54%**	0,11	**98,37%**	0,38	**97,40%**	0,61	**96,92%**	0,72	**96,59%**	0,79	**96,41%**	0,84
August	**99,54%**	0,11	**98,45%**	0,36	**97,58%**	0,57	**97,16%**	0,67	**96,63%**	0,79	**96,46%**	0,83
September	**99,51%**	0,11	**98,63%**	0,32	**97,94%**	0,48	**97,59%**	0,56	**96,81%**	0,74	**96,70%**	0,77

Figure 7. Table of reduction percentages and temperatures reached after simulation of the strategies. Cases of Badajoz (a), Évora (b), Porto (c).

In order to estimate the energy savings that could be achieved by the different strategies for the warmer months, the reduction in energy demand for cooling in the
3 schools as if they had an air conditioning system installed. The data obtained show higher savings for the cases of Badajoz and Évora when the night ventilation strategy is applied.

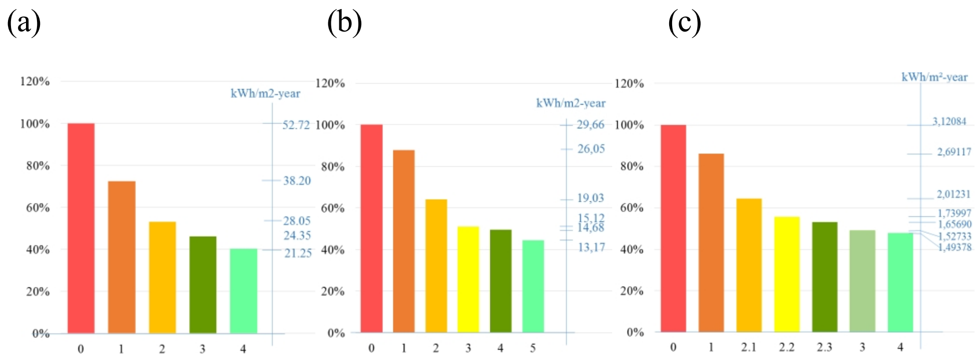


Figure 8. Annual rate of energy demand for cooling according to the application of bioclimatic strategies. (a) Badajoz; (b) Évora; (c) Porto.

6. <u>CALCULATION OF OPENINGS FOR NATURAL VENTILATION</u>

This section presents an example of the calculation of the free area of opening of openings that would be necessary to obtain adequate ventilation flow rates according to the usual methods. The ventilation rate is established by calculating the number of hourly renovations required.

according to climatic conditions. This flow must be incorporated into the building, if possible through passive strategies. That is, relying on natural ventilation.

Natural ventilation models of spaces usually include different variables in which thermal gradients, pressure gradients, wind speeds and impact orientations on the facades, window openings, and the arrangement of openings in the facades play an important role (UNE-EN 16798-7 Calculation methods for determining air flow rates in buildings including infiltrations).

A comparative study of openings has been carried out following the procedures described in *ASHRAE*[11] and in the Technical Building Code document[12] . Those used for the case of Badajoz are discussed.

ASHRAE MODEL. With wind.

$$\mathbf{A=Q/EW}$$

A = Free opening area (m)^2

Q = Design flow rate (m^3 */s). Q = 214.74 l/s = 0.21474 m3/s (Required flow in l/s x person, see Table 1).*

Table 1. Comparison of flow requirements for educational centers.

Surface area (m)^2	Height (m)	No. of students	Flow rate (l/s) x person	*Flow (l/s) Total*	*CATEGORY FIRST LEG 3*
54,44	*2,84*	*25*	*8,6*	*214,74*	*RITE*
			2,2	*119,77*	*ASHRAE*
			6,0	*326,64*	*EN 15251 (CatI)*
			4,2	*228,65*	*EN 15251 (CatII)*
			2,4	*130,66*	*EN 15251 (CatIII)*

E = Effectiveness of the opening (0.5-0.6, perpendicular winds; 0.25-0.35 diagonal winds). E = 0.25 (the values of the wind gusts in °, oscillate around 10°, predominantly coming from the North, therefore they are considered totally diagonal with respect to the facades studied).

W = Wind speed (m/s). W = 1.4 m/s (mode value, obtained from the average speed values for each of the days in the period from May 1, 2019 to October 25, 2019. Source: AEMET

$$\mathbf{A = 0.21474 / (0.25 \cdot 1.4) = \underline{0.613\ m^2}}$$

ASHRAE MODEL. In absence of wind (only pressure and temperature gradients).

$$A = \frac{Q}{1116\sqrt{h(Ti - To)}}$$

A = Free opening area (m)^2

Q = Design flow (l/s). Q = 214.74 l/s (Required flow in l/s x person).

[11] https://www.ashrae.org/
[12] https://www.codigotecnico.org/

h = Height between entrance and exit opening (m). h = 1 m (Considering that it enters through the lower part of the window and exits under the classroom door or exits through the upper part of the window opposite).

Ti = Indoor temperature (ºC); To= Outdoor temperature (ºC): ΔT = 7 (This takes into account the lowest temperature difference between outdoors and indoors during the nights -from 0:00 to 7:00 h-, of the typical summer week).

$$A = 214,74 / (116\sqrt{(1(7))}) = \underline{0.699\ m^2}$$

MODEL CTE-HS3

Model of the Technical Building Code DB HS: Health. HS3: Indoor air quality. This model is used for mixed or hybrid systems. In this case an approximation is made for natural ventilation.

Intake openingsMax (4·q_v or 4·q_{va})

Exhaust openingsMax (4·q_v or 4·q_{ve}) Pass-

through openingsMax (**70**

cm² or 4·q)$_{vp}$

(Ventilation openings (in cm)²

q_v : minimum required ventilation flow rate of the room (takes into account the flow rate per m² . Source: ASHRAE).

q_{va} : ventilation flow rate corresponding to each room intake opening (according to ASHRAE). q_{ve} :

ventilation flow rate corresponding to each room exhaust opening (according to ASHRAE). q_{vp} :

ventilation flow rate corresponding to each room pass-through opening.

Considering the same value of minimum flow rate (q) for all openings, the value obtained in case of mechanical or hybrid ventilation system would be:

$$A = 4 \cdot q = 4 \cdot 0{,}11977^* = 0{,}\underline{479\ m^2}$$

In this case and as a conclusion of the analysis, of the three previous calculation options, the most unfavorable would be the one performed in the absence of wind, by the ASHRAE method, so that the value of 0.70 m² could be taken as valid.

7. NATURAL VENTILATION SCHEMES

Figure 9. Image illustrating adequate ventilation flows in a building designed with bioclimatic architecture concepts in mind.

When considering the application of bioclimatic architecture criteria in new buildings, the orientation of the building itself and its openings is considered. In the absence of wind, ventilation can be produced by the effect of a difference in pressure between one opening and another, which can be achieved by a difference in temperature or pressure due to the effect of height. Figure 9 shows an illustration of cross ventilation flows in a building that takes into account bioclimatic architecture criteria. This section will review the types of ventilation with passive elements that exist and will highlight those that can be used inside schools.

- **Natural cross ventilation**. This type of ventilation generates an air flow by opening two or more points connected to the outside, but at a similar level, on opposite or adjacent walls of the same space. With this configuration, the air quality is improved, although it also affects the indoor temperature, being more suitable for warm climates and seasons.

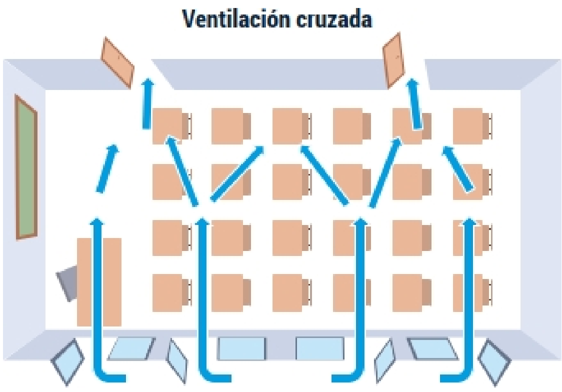


Figure 10. Schematic for natural cross ventilation in a classroom[13] .

[13] Preventive guide for ventilation in classrooms. Instituto de Diagnóstico Ambiental y Estudios del Agua, IDAEA- CSIC, Mesura. María Cruz Minguillón, Xavier Querol, José Manuel Felisi and Tomás Garrido. October 2020

There are other natural ventilation alternatives that allow the ventilation of the building as a whole, but require specific installation:

- **Chimney ventilation**. This is a complex configuration, in which a hollow structure (ventilated roof) installed on the facade or wall cools the air entering from below and carries it upwards. This natural ventilation system is more complex, but is effective for convective cooling at night to[14] .
- **Evaporative cooling**. It consists of passing a stream of warm, dry air through a wet or wet surface to increase the humidity of the air, so that the water absorbs some of the heat to change from liquid phase to water vapor, cooling the air mass, providing humidity and freshness to the air. This type of ventilation is suitable for hot, dry climates and can be used in combination with other natural ventilation systems, such as stack ventilation[15] .

Given the conventional architecture of the classrooms, natural cross ventilation is the best fit in the usual architecture of educational centers. Considering the location of these opening points in a conventional classroom with windows and classroom access door facing each other, Figure 11 shows 3 different opening options (R2 to R4), compared to the zero alternative (R2 to R4).[13] shows 3 different opening options (R2 to R4), as opposed to the zero alternative (R1), in which the room is closed.

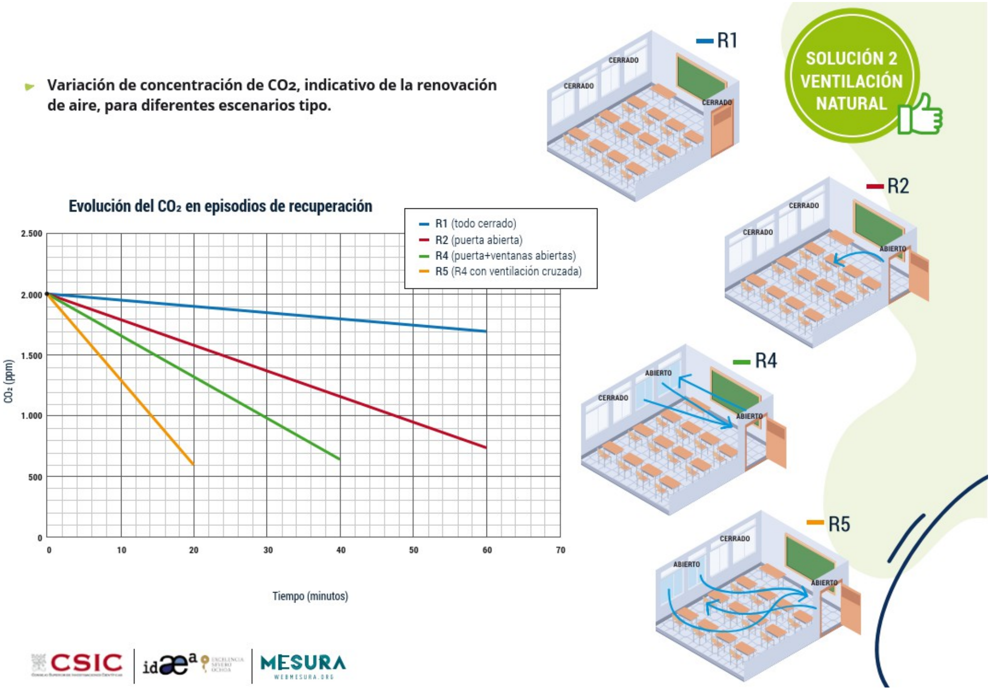


Figure 11. Ventilation flow alternatives and variation of CO concentration₂ associated with each of them. Source: CSIC.

[14] Shouib Nouh Ma'bdeh, et al. Simulation study for natural ventilation retrofitting techniques in educational classrooms - A case study, Heliyon. 6, Issue 10,2020, e05171, ISSN 2405-8440.
[15] Sara Mohamed et al. The impact of a passive wall combining natural ventilation and evaporative cooling on schools' thermal conditions in a hot climate, J. of Building Engineering. 44, 2021, 102624, ISSN 2352-7102.

The concentration of CO_2 in air is a commonly used parameter to evaluate the efficiency of indoor ventilation.[14,16]. Thus, a higher concentration of CO_2 in a room is indicative of poor ventilation, while the opposite implies that ventilation is efficient.

As can be seen in the graph, the decrease in CO concentration$_2$ is already significant in the R2 case (only the door open), but improves significantly with the opening of the windows. But it is the non-facing ventilation option (crossed, R4) that obtains the best results in terms of ventilation efficiency in the shortest time, in 14 minutes it is possible to reduce the CO values$_2$ by half.

However, there are other factors to consider when assessing the efficiency of the ventilation system, such as thermal comfort. The following analysis shows the effect of natural cross ventilation on the interior temperature of the room. In the simulation, carried out with the *Optivent* tool *2.1*[17] , two hypothetical situations have been modeled: **Case 1**, in which the classroom is ventilated exclusively with an open window and the classroom door closed, and **Case 2**, in which cross ventilation is created by opening the window and the classroom door, both facing each other. A schematic representation of both is shown below.

[16] Jørn Toftum, Birthe U. Kjeldsen, Pawel Wargocki, Henriette R. Menå, Eva M.N. Hansen, Geo Clausen, Association between classroom ventilation mode and learning outcome in Danish schools, Building and Environment, Volume 92, 2015, Pages 494-503, ISSN 0360-1323.

[17] http://optivent.naturalcooling.co.uk/OV21/optivent/optivent.php?language=es#close

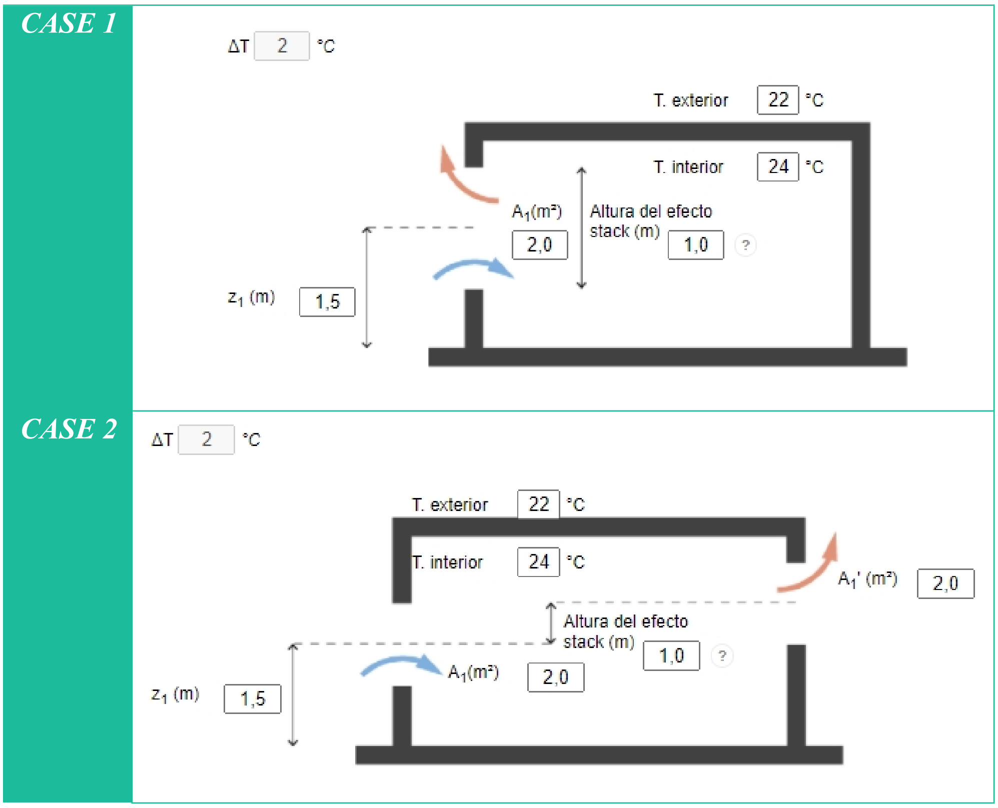


Figure 12. Schematic representation of the cases studied.[17]

In both cases, the starting data were:

- Classroom dimensions: 80 m^2 (8m x 10m) x 3 m
- Standard openings at 50%.
- Class of 30 students, in June at 1 pm.
- Location: Latitude compatible with Solana / Évora.
- Wind speed of 3 m/s, average outdoor temperature 32ºC, ventilation facade facing east.
- First floor classroom, with an exposed wall and covered ceiling.

In general terms, it is observed that the total heat extracted by opening the door and creating current (**Case 2**) is significantly lower than **Case 1**, with a total difference of 0.18 kW, a decrease of 3%.

Table 2. Comparative simulation results: total heat generated[17] *.*

PARAMETER	Units	Case 1	Case 2
Total int. earnings	W/m^2	53.88	53.88
Total solar gains	W/m^2	16.75	14.47
Total heat generated	kW	5.65	5.47

The increase in air velocity is also evident, reaching the highest air flow rate in **Case 2** with external wind (1.09 m^3 /s). The following table shows the data obtained in detail.

Table 3. Comparative simulation results: air flows[17] *.*

AIR FLOW	Units	Case 1		Case 2	
		No wind	Windy	No wind	Windy
Required fresh air flow	m /s^3	0.30	0.30	0.30	0.30
Required for refrigeration	m /s^3	2.35	2.35	2.28	2.28
Reached	m /s^3	0.06	0.25	0.16	1.09

Graphically:

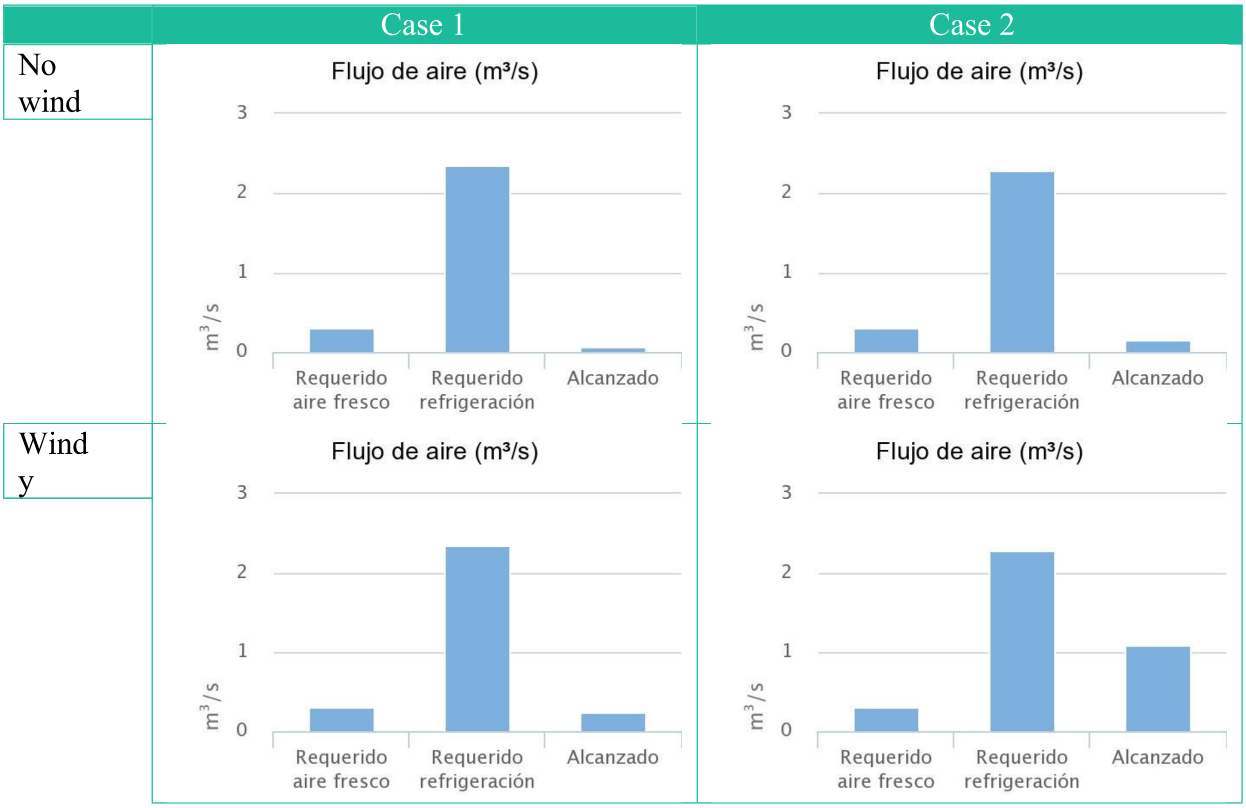


Figure 13. Comparative airflow charts .[117]

The following graphs show the values of room operating temperature versus outside temperature. The blue and gray bands delimit the comfort zone. As can be seen, in only one case (Case 1 with wind) are the temperature values within the comfort zone.

Case 1	Case 2

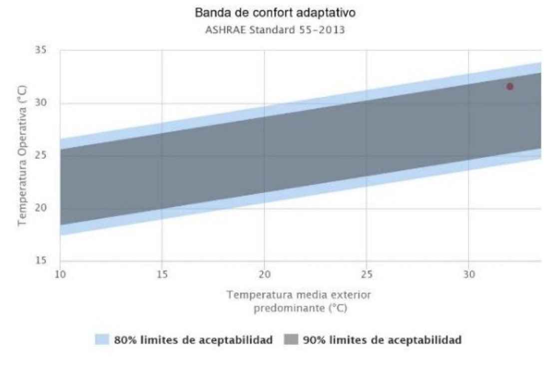
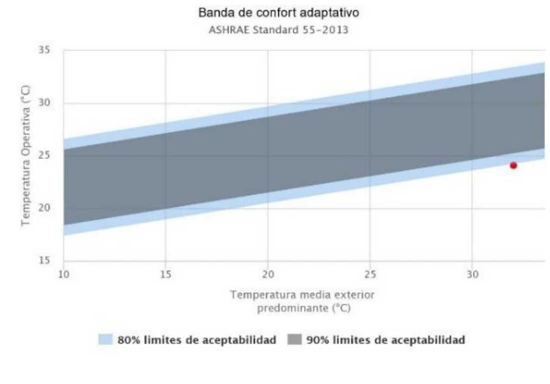
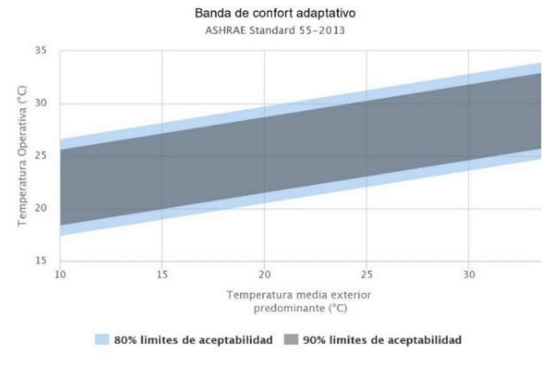
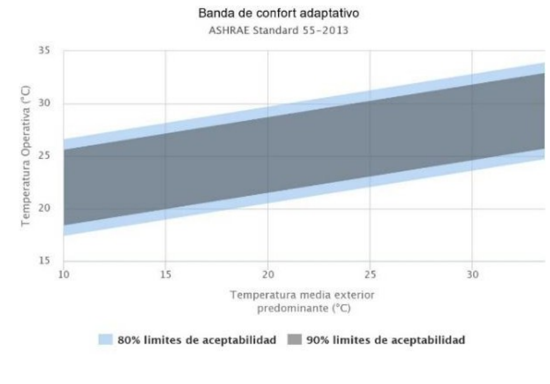
Windy		
No wind		

Figure 14. Comparative graphs of adaptive comfort .[117]

In conclusion, although cross ventilation in the classroom is an effective method in reducing CO_2 in the room and, therefore, in air renewal, it is not enough by itself to achieve an adequate temperature. In the locations studied, towards the end of spring or beginning of summer, additional structures or mechanisms, such as those promoted by LIFE myBUILDINGisGREEN, would be necessary to moderate the indoor temperature to values compatible with thermal comfort.

8. ROOM FOR IMPROVEMENT

In LIFE myBUILDINGisGREEN, as mentioned above, in addition to considering in the bioclimatic strategies the renewal of indoor air using outdoor air when thermo-hygrometric conditions make it advisable, we have included the use of vegetation solutions to improve thermal comfort in the classrooms.

In this sense, a laboratory experiment was carried out to evaluate the possibility of using green surfaces inside the building or in the areas where the air enters the building to reduce the temperature and regulate the humidity of the building.

First, a simple installation was designed to control the temperature and air flow at the entrance to a chamber into which the plant part was introduced. Figure 15 shows the test chamber with the temperature indicators and the rotameter used in the study.

Figure 15. Experimental facility used in the study.

To maintain a stable inlet temperature, the entire system was introduced into a room thermostatted at 30 ºC and the air, coming from a compressor, was circulated through the chamber before entering the chamber to reach the chamber temperature. The chamber inlet temperature was measured in the duct before entering the chamber. In addition, the temperature inside the chamber was measured to study the impact of vegetation. The experimental conditions have been deliberately modified to identify the possible impact and exacerbate the differences between systems. The proportions of plant quantity and chamber volume are greatly enlarged in relation to what could be installed in a conventional classroom according to current standards and tastes and the air flow rates used are very high.

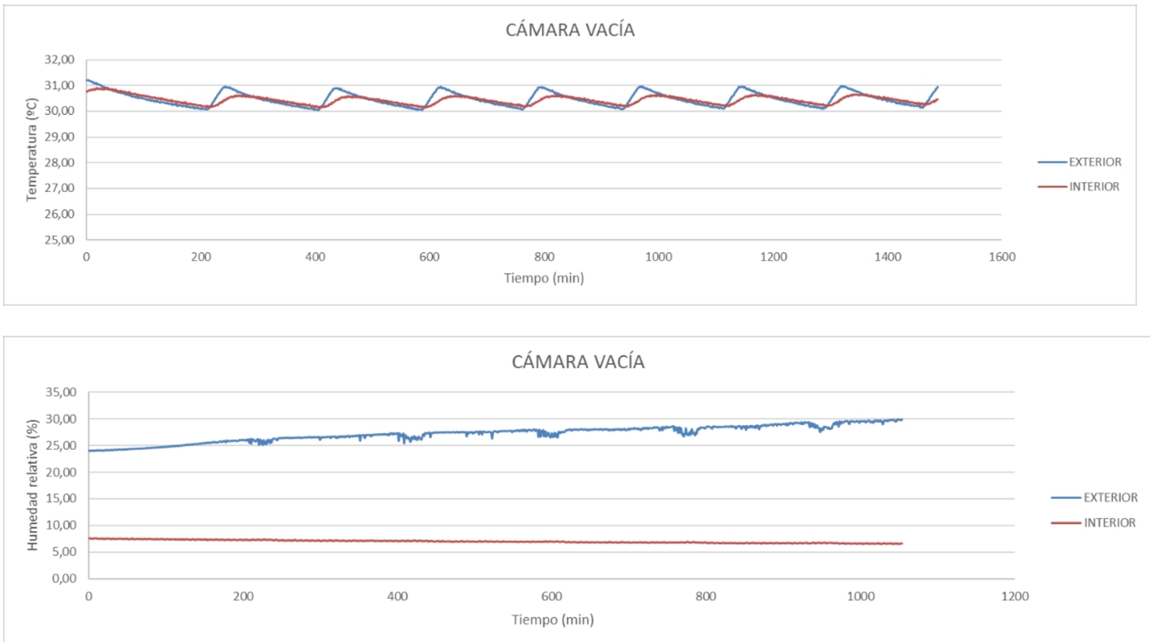
higher than those that can be achieved by natural ventilation for most of the occasions. We want to show these aspects in order to put the study in situation.

After a series of preliminary tests to establish the parameters to be used in the study, the following experimental conditions common to all the tests were defined.

Table 4. Experimental conditions of the tests to be carried out.

Parameter	Value
Air flow rate	10 - 15 - 20 liters/min
Camera volume	3L
Vegetable dough	20 g
Water mass pre-test irrigation water	40g
Type of interior mix	Complete mixing by fan inside

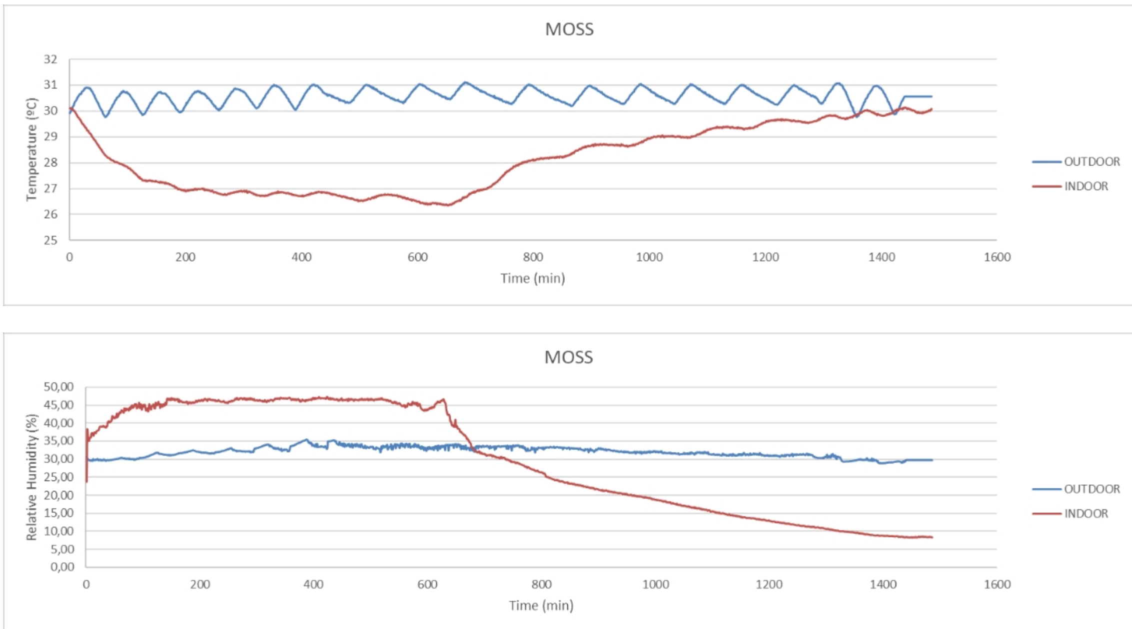
Several tests were carried out to study the procedure and to find the operating conditions that would allow the impact of the vegetation to be appreciated. Figure 16 shows the evolution of temperature and humidity at the entrance and inside the chamber. As can be seen, the temperature profiles are very similar. It can only be seen that the interior temperature is less affected by the thermal variations of the thermostatted room. The humidity profiles show the difference between the arrival air, with humidities between 25 and 30% and the humidity inside the chamber where the temperature increase is noticed and the relative humidity drops to values around 7%.



Temperature and humidity evolution graphs at the inlet and outlet (inside) of the empty chamber.

To study the impact of the type of vegetation that can be used in solutions in these transition zones, three types of vegetation that can be used were selected. F i r s t l y , a conventional plant in a plant container, a feverfew (*Tanacetum parthenium*) in a pot of half a liter of substrate volume and 12 cm plant height. The second system used is a piece of the mBiG WTray system with fescue (*Festuca gautieri*). Finally, a type of moss (*Syntrichia Ruralis*) was also used in the study.

Figure 17 shows the temperature and humidity evolution graphs at the entrance and inside the chamber with moss and an air flow of 10 L/min. As can be seen, the temperature of the chamber is significantly reduced (more than 4ºC at the moment of maximum) while the vegetation has humidity. When it dries out, the evapotranspiration capacity is significantly reduced and the temperature reduction capacity disappears.



Temperature (top) and humidity (bottom) evolution graphs of the experiment carried out with moss and an air flow rate of 10L/min.

Table 5 shows a summary of the results obtained during the tests. As can be seen, the introduction of vegetation leads to a reduction in temperature and an increase in the relative humidity of the air in a room.

Table 5. Summary of the results obtained during the tests.

						Average diff.		max. diff .	
	Flow rate (L/min)	T inlet (ºC)	H input (%)	T chamber (ºC)	H chamber (%)	T (ºC)	H (%)	T (ºC)	H (%)
Empty chamber	10	30,43	26,98	30,49	6,23	0,06	-20,8	0,37	25,46
Wtray	10	30,72	35,25	29,09	24,60	-1,6	-10,7	1,86	13,14
Wtray	15	30,74	35,14	28,62	25,44	-2,1	-9,7	2,38	28,38
Wtray	20	30,79	35,01	28,62	25,44	-2,2	-9,6	2,41	28,25
Moss	15	30,29	31,15	26,40	37,48	-3,9	6,3	4,44	22,33

Table 5. Summary of the results obtained during the tests.

	Flow rate (L/min)	T inlet (ºC)	H input (%)	T chamber (ºC)	H chamber (%)	Average diff. T (ºC)	Average diff. H (%)	max. diff . T (ºC)	max. diff . H (%)
Moss	20	30,44	31,79	26,49	34,37	-3,9	2,6	4,41	26,10
Moss	10	30,58	33,08	26,79	45,13	-3,8	12,1	4,22	23,85
Matricaria	10	30,56	27,41	29,36	16,10	-1,2	-11,3	1,36	16,99
Matricaria	15	30,56	30,50	29,16	15,95	-1,4	-14,6	1,66	18,42
Matricaria	20	30,64	26,82	28,82	15,98	-1,8	-10,8	1,92	14,88

The table above shows how, for all species, the greater the air flow, the greater the reduction in temperature that can be obtained, the greater the evapotranspiration. In principle, this reduction will reach a maximum beyond which the system will no longer be able to sufficiently cool all the incoming air.

In relation to the species studied, moss (*Syntrichia Ruralis*) is the one that performs best. This fact may be associated to the high proportion of leaf surface in relation to the total plant surface and to the fact that they are species with a large number of stomata and low regulation of their opening in relation to the temperature of the environment (in general they keep them open for a long time). Next comes the fescue (*Festuca gautieri*) with between 1.6 and 2.2 ºC of reduction. It is an herbaceous species, whose values are almost half those of moss. Finally, we have feverfew (*Tanacetum parthenium*), the species with the smallest leaf area in relation to the whole plant. Figure 18 shows images of the species used in the study.

Figure 18. Plant species used in the study.

The main conclusion of the study is that the introduction of vegetation in the classrooms or in access areas to the classrooms inside the building reduces the indoor air temperature. Of course, the relationship between the volume of the room and the surface or amount of vegetation introduced is a determining factor in the amount of energy captured by the system and therefore in the temperature of the room. This study is limited to the experimental conditions established and the absolute values collected cannot be extrapolated.

To optimize the use of vegetation indoors, once the necessary openings have been calculated, it will be necessary to evaluate the main air intake zone according to the prevailing wind conditions and the temperature difference between the facades of the opening openings. In this way, it will be convenient to place the elements with vegetation in the areas where the air enters the building or classroom so that their impact is greater. In addition, as we have seen, it is very important to maintain irrigation levels of vegetation to ensure evapotranspiration and its maintenance. Although the impact of vegetation at low temperatures (below the minimum comfort temperature) has not been studied to see if a positive impact could be obtained, it is believed that this system is of interest mainly for hot periods and has a greater impact at high temperatures. Leaf stomata open more the higher the temperature (within limits and selecting the right species) and produce a higher evapotranspiration.

The NBS to be installed in the schools (trees, green roofs, green facades...) also have an impact on indoor thermal comfort, in addition to ventilation. Figure 6 shows how the NBS in each school help to reduce temperatures along with ventilation.

9. VENTILATION PROTOCOLS

In this section, based on the above information, a ventilation protocol has been defined for the classrooms in order to maintain the thermo-hygrometric conditions within thermal comfort levels for the occupants and minimum air quality conditions.

It should be mentioned that the optimal conditions would be found in much narrower ranges than those used, but these conditions could only be ensured during an extended period of school hours using active measures such as air conditioning equipment. Taking into account that installing this type of equipment in all classrooms is not considered a measure that should be extended and knowing the current situation of the classrooms, it is considered more appropriate to implement solutions such as those referred to above, both from an economic and sustainability point of view.

As reference values to be maintained inside the classrooms, assuming a sedentary activity in them, a range of temperatures between 14 and 25ºC and relative humidity between 30 and 60% is established. On the other hand, in relation to CO values$_2$, and after the outbreak of the COVID-19 pandemic, a maximum of 700 to 800 ppm is recommended. This reduces the risk (below 1%) for a classroom type, that the air breathed by one person can be inhaled by another.

There are many different types of classrooms and contexts. Therefore, first of all, a prior protocol of the situation is established in order to define the best solution. It must be taken into account that, as in most of the occasions there will not be the possibility of automating the openings, there will have to be people in charge of carrying them out. Therefore, it is considered necessary to study the environment in order to reduce to a minimum the number of interventions necessary to carry out the ventilation, generating the minimum disturbance.

- To have the climatic data of the area. In particular, temperature profiles will be necessary.
- Analyze the profile of temperatures, humidities and CO concentrations$_2$ of the interior of the classroom that you usually have. This can be done using the records of the meters that many classrooms have during a week that can be representative. The longer the period under analysis, the better the picture can be obtained of the initial situation.
- Determine for each classroom:
    - Basic information about the classroom including orientation, a floor plan with dimensions, location of stalls, openings and their dimensions.
    - Average classroom temperature during the school period. Relevant information to establish priorities in the educational center if necessary.
    - Time in the morning when indoor temperature values above 25 ºC are reached in each classroom. The temperature range for sedentary activities is between 14 and 25ºC.
    - Temperature and humidity at the beginning and end of the standard school period.
    - CO concentration profiles$_2$ during the school period and maximum values along with the times of day at which they occur.

LIFE myBUILDINGisGREEN considers thermal comfort and indoor air quality in schools to be of great importance. Within the process of adapting schools to climate change, one of the key aspects is to ensure that indoor conditions are suitable for the expected teaching and recreational activities. Climate models predict, as we are already seeing, a significant increase in the average temperature and in the intensity and duration of heat waves in southern Europe. In view of this scenario, it seems essential to study how to avoid the heating of school interiors during the hottest periods that coincide with the school term. The installation of active systems to modulate environmental conditions such as air conditioning systems cannot be recommended, since there are other passive possibilities that combine the criteria of bioclimatic architecture, the use of solutions based on nature (which also have other associated benefits) and other measures without a major environmental impact or increased energy consumption.

In principle, the proposed procedures can lead to diagnoses that could be made with a simple knowledge of the field. However, it was deemed necessary to systematize in a certain way the identification of problems, the proposal of solutions and simple calculation indicators to help assess the impact of the actions carried out. LIFE myBUILDINGisGREEN is working on a tool to assist stakeholders in the selection of practices and measures to improve thermal comfort and indoor air quality in schools.

The tool is still under development and will be completed at the end of the project. It will be validated with the interventions carried out in the schools with prototype NBS and when the proposed ventilation protocols have been tested. The tool is an Excel file that will allow the basic information discussed above to be entered for each location. With this information, and in a series of result sheets, it will show the diagnosis for each of the parameters to be evaluated (temperature, relative humidity and CO concentration$_2$) and will guide the user on the recommendations made by LIFE myBUILDINGisGREEN to adapt buildings to climate change and ensure adequate thermal comfort and air quality conditions. This tool can also be used later to assess the impact of the actions carried out.

Below are some images of the tool in its current beta version. It is very possible that some of them will be modified in the final version that will be published as a result of the project.

Figure 19 shows an image of the initial screen used to collect basic initial information, including the records of the classroom in question. From this screen it will also be possible to access the rest of the information that will be used to make diagnoses and to study the recommendations.

FECHA	HORA	[CO2] [p	T [°C]	P [mbar]	[%HR]	Text [ºC]	[%HR] ext
06/05/2019	15:30	547	25,8	987	39,8		
06/05/2019	15:45	552	25,8	987	39,9		
06/05/2019	16:00	538	25,8	987	40		
06/05/2019	16:15	540	25,9	987	40,1		
06/05/2019	16:30	533	25,9	987	40,1		
06/05/2019	16:45	524	25,9	987	40,1		
06/05/2019	17:00	518	25,8	987	40,1		
06/05/2019	17:15	503	25,8	986	40,1		
06/05/2019	17:30	490	25,8	986	40,1		
06/05/2019	17:45	482	25,7	986	40,1		
06/05/2019	18:00	473	25,7	986	40,1		
06/05/2019	18:15	461	25,7	986	40,1		
06/05/2019	18:30	458	25,6	986	40,1		
06/05/2019	18:45	452	25,6	986	40,1		
06/05/2019	19:00	439	25,6	986	40,1		
06/05/2019	19:15	438	25,5	986	40,1		
06/05/2019	19:30	437	25,5	986	40,1		
06/05/2019	19:45	441	25,5	986	40,1		
06/05/2019	20:00	430	25,4	986	40,1		
06/05/2019	20:15	437	25,4	987	40,1		
06/05/2019	20:30	436	25,4	987	40,2		
06/05/2019	20:45	433	25,4	987	40,2		
06/05/2019	21:00	433	25,4	987	40,3		
06/05/2019	21:15	436	25,4	987	40,3		
06/05/2019	21:30	425	25,4	987	40,3		
06/05/2019	21:45	428	25,4	987	40,3		
06/05/2019	22:00	435	25,3	987	40,3		
06/05/2019	22:15	435	25,3	988	40,2		
06/05/2019	22:30	438	25,3	988	40,3		
06/05/2019	22:45	430	25,3	988	40,3		
06/05/2019	23:00	428	25,3	988	40,3		
06/05/2019	23:15	433	25,2	988	40,3		
06/05/2019	23:30	432	25,2	988	40,3		
06/05/2019	23:45	434	25,2	988	40,3		
07/05/2019	0:00	430	25,1	988	40,3		

Figure 19. Image of the initial sheet of the tool.

Once the classroom records have been entered, it allows you to visualize graphically the evolution of each of the parameters and to visually assess the records that fall outside the range of the recommended values. Figure 20 shows an image of the tool sheet in which you can view the CO profiles$_2$ recorded and a summary of the indicators calculated to assess the state of air quality. The evaluation is carried out on a monthly basis so that, if the records for a whole year are entered, a complete view of when possible air quality problems are concentrated in the classroom can be obtained. In addition to indicating the average, maximum and minimum values, it indicates the number of records that have exceeded the recommended values and the % of them. By default, it has been established that, if the records with a concentration above 750ppm exceed 20% of the measurements, it is considered that action is required. This value of 20% can be modified in case the user would like to use another value.

There are two similar sheets for temperature and humidity that allow a similar diagnosis for these parameters. This makes it easy to identify the months in which episodes of thermal discomfort or poor air quality occur.

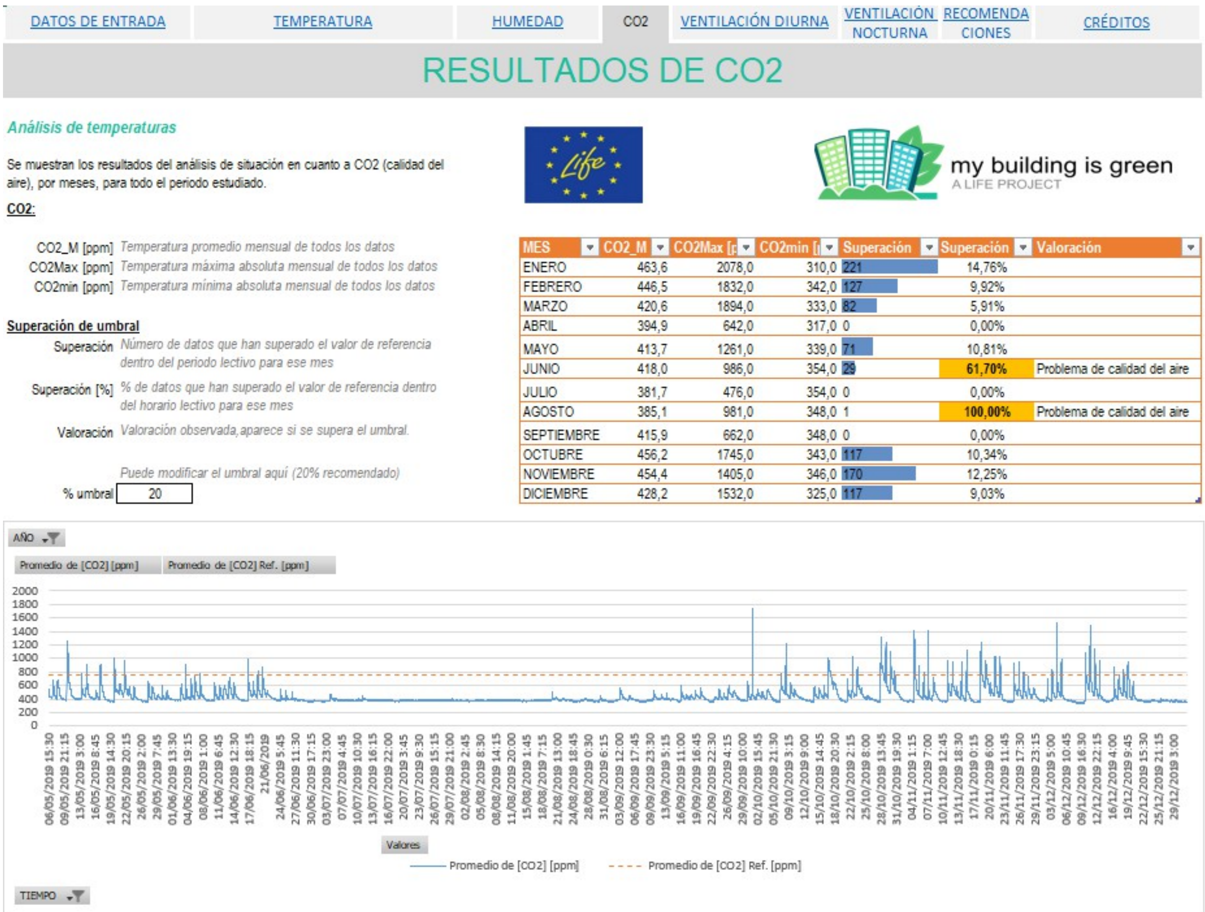


Figure 20. Image of the sheet in the tool showing the profile of CO concentrations$_2$ recorded.

- **TEMPERATURE**. Evaluate with the temperature profiles if during more than 10% of school time in the months of May, June and September, the values recorded exceed the maximum referred to or do not reach the minimum mentioned above (low temperatures are not the subject of this Project). If temperatures exceed the established values, the recommendations of the action procedure should be followed to reduce the temperature inside the classroom by using outside air and as far as possible apply Nature Based Solutions such as shading of openings or areas surrounding the building, green roofs or the installation of interior green walls.
  The temperature range considered valid would be from 14 to 25ºC. The maximum temperature indicated for health reasons would be 27ºC. The maximum temperature value can be modified in the initial sheet.

- **RELATIVE HUMIDITY**. First, calculate the average value of the measurements collected during the school period and check if it is within the range mentioned[18] . If this value is outside, evaluate with humidity profiles if for more than 20% of the time the recorded values are outside the range.

[18] Relative humidity between 30-60%.

established. If so, the recommendations of the action procedure should be followed to raise or lower humidity levels as appropriate.

The humidity range considered as valid is between 30-60 %. Both values could be modified in the initial sheet if the user considers that the characteristics of his case make it advisable.

- **CO CONCENTRATION$_2$** . Evaluate with the carbon dioxide concentration profiles whether the established maximum values are exceeded for more than 5% of the time. On the other hand, it is also interesting to determine the time it takes to reach these maximum values with all the people in the classroom and with the openings completely closed. This is a test that has to be carried out in the classroom itself with all the usual people present. The main solution to be applied is natural ventilation by opening openings following the recommendations described in the action procedure.

  CO concentration levels$_2$ should not exceed 750 ppm. This value can be modified in the initial sheet in case you want to adapt it to the case study. Before the COVID-19 pandemic, the reference value used was 1000ppm and was aimed at not affecting the students' ability to concentrate. In the current situation, the aim is to reduce the risk of contagion if there is an infected person in the room.

Procedure for action:

When **temperature** levels exceed the recommended levels, the procedure to follow is:

- During the hottest months of the year, when indoor temperatures are higher than 26-27ºC, it is advisable to take advantage of the night to ventilate the school and classrooms to cool them down. The objective is to reduce the interior temperature (lowering the thermal load of the building) during the night and to start the school timetable with the lowest possible temperature (in the hottest period of the school year, normally the second half of May, June and September). The lowest indoor temperature obtained is in principle within the comfort range.
- Once the classroom temperature reaches 25-26 ºC (depending on the users), a wind speed of between 1 and 2 m/s should be encouraged to reduce the thermal sensation by 1 to 2 ºC. If the outside temperature does not allow air movement by cross ventilation, mechanical elements can be used to move the air such as ceiling or floor fans.
- Shade openings from the outside with natural deciduous solutions that allow blocking solar radiation during the hottest periods and continue to take advantage of solar radiation during the coldest periods. Design the solution so that part of the visible fraction can enter to maintain adequate lighting levels. It is very important that the blocking of radiation is done from the outside, otherwise the classroom will be heated. In addition, it is advisable to use natural solutions that can modulate their temperature through evapotranspiration so as not to increase either the level of reflected radiation or the outside temperature.
- In areas with more than 20% of the school period (or less if it is considered that serious damage is being generated) above the maximum recommended temperature, 27ºC, it is necessary to implement one of the following measures:
  - Seasonal shading systems for openings. See mBiG vertical solutions.

- Install automated systems for opening openings and supply air to force air through the building during the night period.
- Install interior green walls in areas of air entry or circulation to promote evaporative cooling through the control of vegetation irrigation.
- Evaluate the feasibility of implementing a green roof to reduce the insolation of the building's roof. Classrooms on upper floors under the roof.
- Install mechanical ventilation systems in classrooms to generate air movement.
- Audit internal heat sources and implement an equipment shutdown plan, if necessary with programmed shutdown systems. In addition to reducing the heat input of certain equipment (computers, projectors, photocopiers, etc.), you will be saving energy.

When **humidity levels are** not in the proper range, the procedure to follow is:

- If the average value is lower than the minimum value of the range (40%) it is recommended to install vegetation inside the classroom. Study the indoor vegetation solutions proposed by LIFE myBUILDINGisGREEN in the published Project documentation. They have been deliberately not introduced in this document in order not to increase the length of the document.
- If the average humidity values are higher than the maximum limit of the range (60%), the cause must first be determined:
    - High room occupancy and low ventilation. People's breathing and perspiration generate ambient humidity. In this case it is necessary to increase the ventilation levels following the indications given in the following point regarding CO levels$_2$.
    - Construction problems (waterproofing and/or insulation failures) or leaks that generate humidity in the classroom.
    - The rainfall regime in the area is very high. This can cause ambient humidity values above the recommended limit when ventilation levels are high. This case has not been considered as an object of study within the Project.

When **CO levels$_2$** exceed the appropriate levels, the procedure to follow is:

- In general, it is recommended to keep the openings open when the outside temperature is within the recommended range. Of course, this recommendation does not apply in cases of excessive outdoor noise or pollutants. During the hottest season, opening openings during the night period allows lowering the thermal load of the classrooms and being able to maintain thermal comfort longer and start the day with a good air quality. In case of places close to important sources of traffic, keep the openings open only during the night hours with less traffic circulation to avoid the entry of air pollutants from traffic.
- From a practical point of view, select two windows or a window and a door on opposite walls, preferably not facing each other, through which to circulate the air.

sweeping as much of the classroom as possible. On the other hand, in times when outside temperatures are not comfortable, ventilation should be carried out for the minimum time to recover initial levels. Ideally, the classroom should be kept between 600 and 750ppm CO_2 .

- Generally speaking, for a typical classroom of about 50m^2 and a height of 3 m with 25 students, with a temperature difference between inside and outside of 4 ºC and a height difference between the air inlet and outlet area of 1 m, the minimum recommended opening surface would be 0.93 m^2 . The recommended surface would be smaller in cases with fewer students, more height difference between ventilation points and more temperature difference between inside and outside (or between one facade and the other where the openings open). The tool can be used to easily calculate the minimum recommended surface area based on the above-mentioned parameters. Also, if there is wind in the direction of the facade where the openings are open, the surface area will also be reduced because there will be more air flow available.

Figure 21. Image of the tool sheet that allows estimating the opening area for ventilation.

- On the other hand, the tool also allows a simple calculation to estimate classroom ventilation times. In general, for a classroom with the conditions mentioned above, it would take about 10 minutes to go from a concentration of 750ppm to a concentration of 450ppm, assuming a complete mixing with an efficiency of 80%. The tool allows an estimation of the time required to achieve this air renewal.
- On the other hand, it is also possible to estimate the time in which a CO concentration$_2$ of 750ppm is reached, starting from an air with 450ppm and 25 people inside. For the classroom of the previous example, with all the openings closed, and assuming a volume expelled per minute of 8 liters per person and a concentration of 4000ppm, the maximum concentration would be reached in 58 minutes. Therefore, a protocol that might be appropriate is that every hour the classroom is kept closed,

the holes should be opened for at least 10 minutes. All this if the openings cannot be kept open all the time, as is logical.

- Likewise, it is recommended to find ways to teach as many classes outdoors as possible (not only those related to physical activity), adapting the available spaces and their scheduling. It is understood that this is a measure that requires adaptation, but LIFE myBUILDINGisGREEN believes it is a highly recommendable measure.
- The tool also allows to evaluate whether night ventilation can be used to thermally condition the classrooms to improve thermal comfort during the following day. It evaluates the outdoor temperature profile in the area to verify that the thermal load inside the building can be lowered.
- Finally, with the above analyses, the tool proposes a series of solutions adapted to the case study from the catalog that LIFE myBUILDINGisGREEN is working on.

Figure 22. Image of the recommendation sheet made by the tool based on the analysis performed.

As mentioned above, only a beta version is currently available for evaluation, which will be completed with the tests carried out during the project after the implementation of the solutions in the schools.

10. ANNEXES

A.1 Climate data analysis.

A.2 Study of bioclimatic strategies.

A.3 Solar calculation.

A.4 Calculation of openings.