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Diagnóstico de sostenibilidad del rendimiento de centros educativos y desarrollo de herramientas para aumentar las competencias de la comunidad educativa.

Diagnosis of the sustainability of the performance of educational centres and development of tools to increase the competences of the educational community.

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Resumen-- **El Proyecto ECF4CLIM co-diseña, prueba y valida un marco de competencias europeo para que la comunidad educativa impulse la transición hacia una economía sostenible y baja en carbono, involucrando a centros educativos de diferentes países europeos. En este contexto se analiza el comportamiento energético y medioambiental de cada centro. Este diagnóstico se está llevando a cabo a través de auditorías y herramientas de análisis. Las auditorías se basan en la recopilación de documentación relevante, y en la realización de visitas y encuestas en los diferentes centros educativos, caracterizando la construcción de los edificios, el consumo de energía y agua y otros parámetros ambientales. Las herramientas informáticas permiten calcular la huella ambiental, identificar las estrategias de rehabilitación adaptadas a las condiciones climáticas y evaluar las intervenciones de sostenibilidad. La aplicación combinada de ambas herramientas proporciona las pautas más adecuadas a implantar en cada centro para optimizar su comportamiento.**

Palabras clave— Sostenibilidad; Educación; Reducción de la huella ecológica; Eficiencia energética; Herramientas digitales.

Abstract— **The ECF4CLIM project co-designs, tests and validates a European competence framework for the education community to drive the transition to a sustainable, low-carbon economy, involving schools from different European countries. In this context, the energy and environmental performance of each school is analysed. This diagnosis is being carried out through audits and analysis tools. The audits are based on the collection of relevant documentation, visits and surveys in the different educational centres, characterising the construction of the buildings, energy and water consumption and other environmental parameters. The IT tools allow calculating the environmental footprint, identifying climate-adapted retrofitting strategies and assessing sustainability interventions. The combined application of both tools provides the most appropriate guidelines to be implemented in each centre to optimise its performance.**

Index Terms— Sustainability; Education; Footprint Reduction; Energy Efficiency; Digital Tools.

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I. Introduction

Climate change has become one of the biggest challenges facing humanity today. In the context of a planet whose population has doubled in less than 50 years and the upward trend continues (World Bank, 2023); Habits have also changed. – The development of industry, technologies and means of transport go hand in hand with the consumption of resources and energy, giving rise to unsustainable and polluting patterns that alter the environment.

The most recent report by the Intergovernmental Panel on Climate Change (IPCC, 2022) shows that climate change is causing severe impacts on both humanity and ecosystems. These impacts lead to increasingly intense and frequent extreme weather events. Therefore, it is essential to quantify the human influence on climate change, to set a limit to the increase in global temperature and to take urgent and effective measures to achieve these goals.

However, there is a growing sensitivity to the effects produced by this change, trying to identify how to act on its causes to mitigate its consequences. In the European Union, a 31% reduction in greenhouse gas (GHG) emissions has been achieved in recent years, exceeding the targets set for the period 1990-2020 by 11%. A new target of at least 55% net reduction by 2030 has been set, requiring the continued implementation of policies and measures across all sectors to mitigate and prevent GHG emissions into the atmosphere (European Environment agency, 2021).

To establish these measures and policies, it is necessary to have a broad focus: causes and origins; where it is polluted and how the carbon footprint is generated.

One of the main sources of GHG emissions is the production and consumption of energy, often based on the combustion of gas, petroleum, or coal derivatives. That is why it is very important to research more efficient and clean energy sources, or to optimize the different ways in which energy is consumed to reduce demand. But energy consumption is not evenly distributed across sectors. The residential sector consumes 28% of the EU's final energy (Fig. 1), like the 28.4% recorded by the transport sector and the 26.1% corresponding to the industry sector, while the services sector accounts for only 13.7% (Eurostat, 2023).

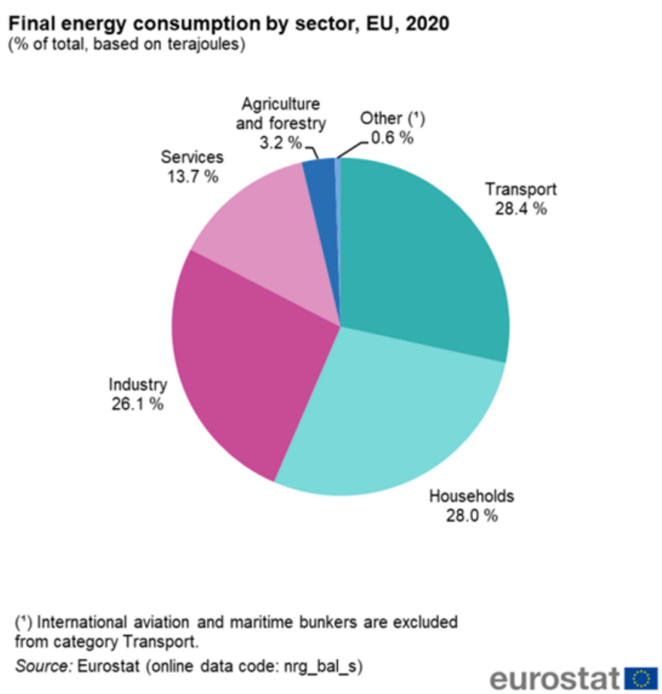

Fig. 1 Final Energy Consumption by Sector in the EU

Energy consumption in buildings is therefore a very important percentage; where consumers and users are basically the citizens. For this reason, schools must play a very important role in two aspects: as points of consumption and pollution, but also as spaces where a new culture of efficiency and sustainability is created (Gamarra et al., 2018; 2019) - in areas such as the improvement of energy efficiency, the use of renewable energies, the reduction of energy consumption - also in the reduction of waste generation, the use of sustainable transport, the shift towards local food, green purchases and the reduction in water consumption.

Schools need to acquire the sustainability skills that allow them to be able to take advantage of their capacity to reduce their carbon footprint (ClimACT, 2023; Lizana et al., 2021). In this context, the ECF4CLIM project (ECF4CLIM-A., 2023) aims to define a European Competence Framework (ECF) for a sustainable and low-carbon economy through education.

This framework reinforces individual and collective competences (knowledge, skills) in the areas of climate change and sustainable development, involving educational centres of different levels and European countries in a participatory way together with public bodies, research centres and companies. To do this, a 4-point structure is followed:

- Co-design of the ECF, in which challenges and opportunities are identified in schools and universities (individual and collective competencies)
- Validation of ECF through a variety of interventions contextually tailored to our case studies (environmental and behavioral)
- Participation in the evaluation of ECF by the educational community (individual & collective drivers and barriers)
- Empower the education community to trigger and sustain transformative change towards a more sustainable future.

Among other tasks, the project analyses the energy and environmental performance of all participating schools

II. Methods

In this work, different actions are carried out to characterize the situation of schools in three stages: audits, development of analysis tools and final diagnosis. Audits in schools define and evaluate their current situation in different environmental and energy areas, in such a way that they make it easier to locate their weaknesses and strengths, their possibility for improvement, and evaluate the improvements that are proposed. On the other hand, specific analysis tools are developed in a simulation space. These tools are related to the environmental footprint, the ability to rehabilitate the centre or the effects of possible interventions. The input information

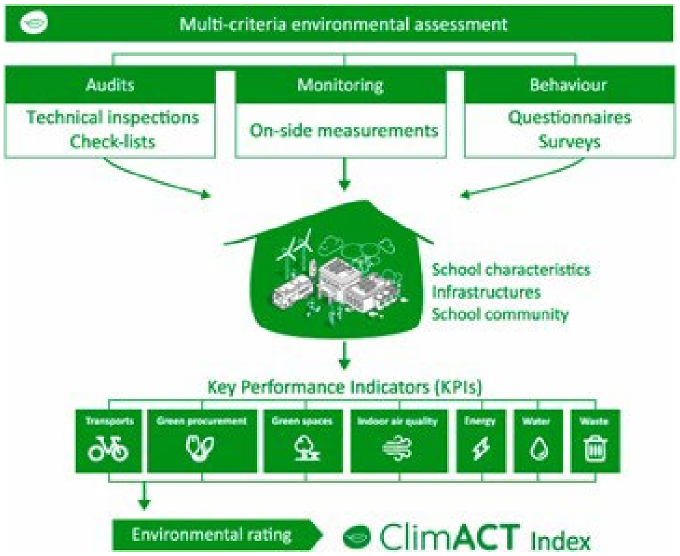

Fig. 2. Implementation of the methodology (source: Lizana et al, 2021)

needed for the tools comes from the data obtained in the audits, and considers different types of users, such as school staff or students' families, but also provides information of great technical utility.

The combination of the results of the audits, their interpretation and their application in the tools developed allows a complete diagnosis to be made of each centre.

A. Audit

The analysis of the state of schools is based on the multi-criteria methodology for measuring and promoting sustainability in schools presented in (Lizana et al., 2021) and shown in Fig. 2.

To monitor the performance of the schools, a series of Key Performance Indicators (KPIs) are defined that are based on the data obtained from the audits. These numerical indicators not only make it possible to evaluate a school and compare it with others, but also to compare its status and behaviour throughout the project, in which it is expected to implement changes in habits and make improvements, through different types of interventions.

In this methodology, 7 fields are proposed: Transport (T), Green Procurement (GP), Green Spaces (GS), Indoor Air Quality (IAQ), Energy (E), Water (Wr) and Waste (Ws). Each of them allows you to obtain both a particular KPI (score or note) and specific KPIs. These values are identified and quantified through a purpose-built template, which provides both general information and quantified data related to these 7 fields. In the same way, you get a global KPI or "Total Score" as an average. This value easily labels each school at a given point in time, making it possible to compare it with other schools and, above all, allowing them to compare their initial and final state after the implementation of the improvements. This number also makes it possible to briefly assess the impact of the changes that have occurred throughout the project.

The application of this methodology and the requirements it entails establish the needs for designing and carrying out audits in schools. These audits, formalised in templates, will provide the descriptive data of each building, and will allow the creation of a database with all the educational centres in the project. The templates for these audits are structured in different tabs, which collect information about the fields defined in the methodology. The highlights of these tabs are described below.

General information: Location, year of construction, number of occupants of the school (students, staff), area (built, gardens).

Transport: Parking spaces in the school or its surroundings (for combustion vehicles, electric cars, for people with reduced mobility, for bicycles). Public transport in the area: distance to the nearest stop, number of stops in different radii, number of lines and frequencies – for different transports: bus, train, tram... Survey among students and teachers about the means they use to travel between their home and school.

Green spaces: Area covered by vegetation in the school; type of vegetation; type and number of fertilizers and pesticides consumed, water and energy consumed in gardening activities.

- Green purchasing: Quantity of equipment with energy efficiency labels; quantity and ecology of wastepaper; food purchased and its origin (by distance).
- Indoor air quality: Data obtained from a monitoring system that will be installed for this purpose in a classroom of the centre, of concentrations of CO, CO2, PM2.5 and PM10 particles and TVOC in the air.
- Energy: Electricity, natural gas, petroleum products or biomass. Consumption in KWh or volume and economic expenditure in the last 5 years.
- Water: Consumption in m3 and economic expenditure in recent years.
- Waste: Volume measurements (different containers and reference bags) of garbage produced, recycled, and composted.

Broadening the approach according to the different needs of the project, three other related templates are developed. One of these templates is intended to characterise the centre's air conditioning and electrical installations. The information obtained from it will be used as a reference when designing the monitoring system to be installed within the framework of the project. This monitoring will consist of the experimental evaluation of between one and three occupied classrooms, obtaining data related to air quality, humidity, ambient temperature, and electricity consumption. The data provided by these monitoring campaigns will be part of the database.

The second template is a "checklist", particularly useful in school visits/audits, where a global view is obtained with measurable information about the building (use of the buildings; user habits; energy production and consumption, ventilation, building envelope, etc.). This template includes additional information regarding the particularities of the centre, such as construction errors to be corrected in possible interventions; or the subjective perception that its users have, for example, of comfort and air quality. From here, the study rooms for monitoring are chosen and defined.

Finally, a third specific template is designed to measure waste every day of a week, specifying the type of waste (more detailed information than that requested in the database for

KPIs).

To complete these audits, a joint work is carried out between educational centres, awarded companies, research centres (including universities) and other institutions such as city councils. We will start from different sources of information:

Documentation of the uses and customs of the centre: Building book: construction materials, architectural plans, distribution diagrams. Consumer bills. Information from public bodies.

Documents relating to sustainability, environmental or energy programmes underway at the centres

Surveys of teachers and students regarding habits (transport)

Sampling Techniques for Specific Measurements (Waste Produced)

On-site visits to schools, with educators, maintenance staff, technical staff. Permanent communication between participants.

B. Tools

A series of tools are designed in a simulation space (Fig.3) with multiple utilities: educational, informative and to help in the decision-making process. The information provided by these tools will facilitate the planning of effective policies that consider the climate impact on the built environment of selected schools and universities, as well as energy efficiency and sustainability improvements.

These tools are aimed at users of different levels: school staff, managers, maintenance managers, students, families, or teachers.

This simulation space consists of three tools, which are described below:

1) Environmental Footprint Calculator

The Environmental Footprint Calculator allows the calculation of the impact associated with student activity considering the typical complete system present in an educational centre. It has been developed based on the multi-criteria and holistic approach offered by Life Cycle Assessment (LCA) following the guidelines of ISO 14040 and ISO 14044.

LCA is a methodology that assesses the environmental impacts associated with all stages of a product's life cycle and encompasses raw material extraction, processing, manufacturing, transport and distribution, use, reuse and recycling, and final disposal. The LCA methodology comprises four phases: (i) Definition of the objective and scope; (ii) Inventory analysis; iii) Impact assessment and finally iv) Interpretation of the results.

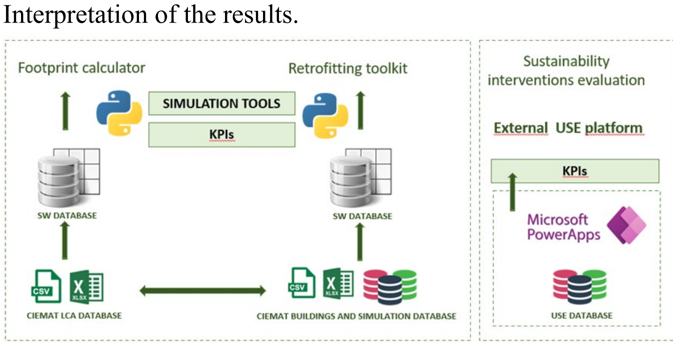

Fig. 3. Space simulation overwiev.

The first step is the identification of the school system according to the purpose, scope, and key components of the school system. The objective of the Calculator is to quantify the environmental impacts associated with the consumption of energy, materials and water of schools located in Europe, and specifically in the regions of Spain, Finland, Romania, and Portugal, where the schools participating in the project are located. The function is the provision of resources necessary for student activity during an annual season, so the results will be those expressed by year and student.

The scope of the system includes the operation and maintenance of the school building, learning, and teaching activities, as well as daily mobility and transportation (excursions, stays); from which to identify the critical points and the potential for environmental improvement. In addition, an additional version of the calculator allows you to include another system, "home", including the consumption of energy, water, transportation, etc. of the students' families. This definition of the system divided into three subsystems has been used and validated in previous research (Fig. 4).

Next, a template was designed to collect input data from schools and households to predefine the information needed to be completed by users, thus creating an inventory (inputs and outputs of material and energy related to each component of the system). Taking into account the inputs and outputs identified, a database of environmental impact factors linked to them was developed that allows the characterization of the impact per student through a method that includes twelve categories of environmental impact grouped into four categories: global impacts such as Climate Change or the destruction of the ozone layer; carcinogenic and non-carcinogenic health impacts; impacts on ecosystems, such as acidification and eutrophication; and, depletion of resources. The ILCD (European Commission, 2011) proposed by the JRC of the European Commission was used as a characterization method. Finally, the results are displayed graphically allowing them to be interpreted.

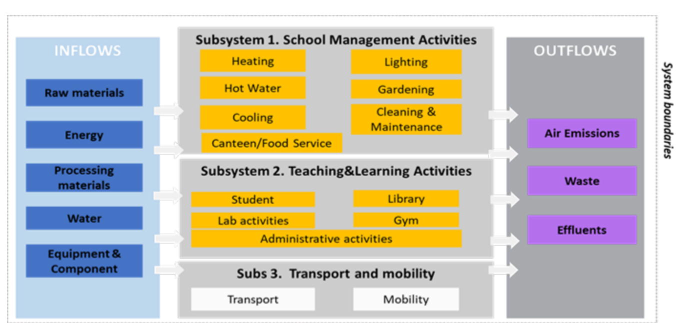

Fig. 4. Representation of the scope and limits of the school's system and subsystems.

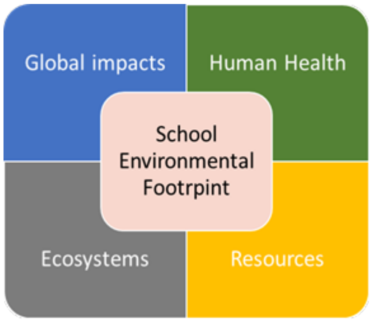

Fig. 5. Groups of environmental impact categories included in the Environmental Footprint Calculator

2) Refurbishment tools

The design of a building under energy efficiency and sustainability criteria depends on different factors: climatology, urban layout, volume, construction variables, windows, dimensions and materials of the shading elements, typology, and use of the buildings. The goal is to achieve high levels of comfort inside these buildings through greater or lesser exposure to solar radiation, the rational use of winds or the modulation of temperature and humidity. One of the elements used to facilitate the efficient and sustainable design of buildings is through surface maps of climatic and energy characteristics. These maps are graphical representations of environmental properties and heating and cooling requirements, allowing indoor thermal comfort levels to be quantified.

With the aim of evaluating the climatic characteristics of each area, identifying the most appropriate strategies for these boundary conditions, and quantifying the annual thermal demands of different construction and operational configurations of buildings, an energy rehabilitation kit has been developed that consists of two new tools:

Tool 1: Surface maps of the local climatic characteristics and the main bioclimatic strategies adapted to the boundary conditions of the schools analysed.

Tool 2: Analysis of the energy efficiency of classrooms by quantifying the potential for savings in the thermal demand of educational centres, through dynamic simulation tools.

This toolkit aims to strengthen awareness and commitment to energy efficiency among teachers, students, managers, and school staff. In addition, it seeks to raise awareness among the educational community about the potential of digital technologies in traditional education and the new ways of using them.

The operating structure of this kit is outlined in Fig. 6.

Tool 1 makes it possible to identify an efficient and sustainable design of buildings using surface maps of climatic and energy characteristics. These maps are graphical representations of environmental properties and heating and cooling requirements, allowing thermal comfort levels inside the building to be quantified. On the other hand, Tool 2 makes it possible to evaluate the potential for savings in the thermal demands of the classrooms by considering different operational and construction conFig.tions of the classrooms. To this end, simulation tools are used to characterize the behavior of the classrooms in short periods of analysis.

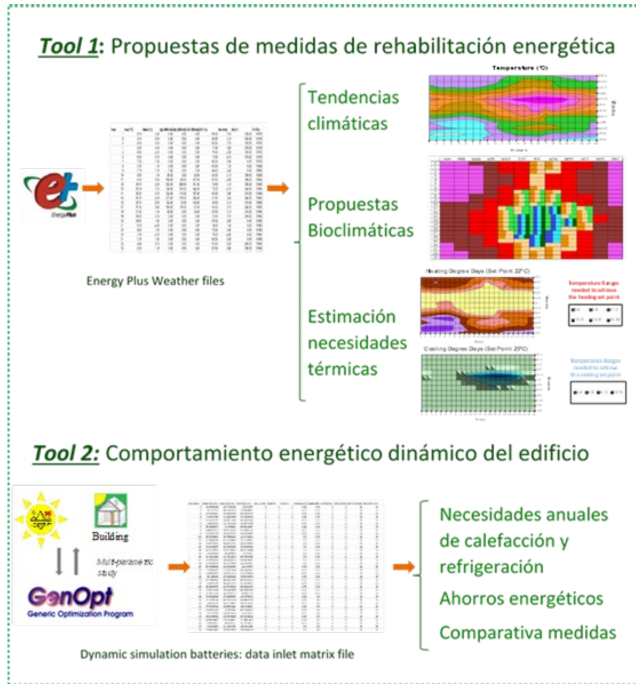

Fig. 5. Operating diagram of the energy rehabilitation toolkit developed within the framework of the project.

This toolkit developed will select the input data for each school, providing as outputs:

- Analysis of the climatic characteristics of the area.
- Identification of different bioclimatic measures to improve thermal comfort within schools.
- Estimation of heating and cooling needs based on set set points.
- Quantification of the thermal needs of a classroom based on the proposed energy efficiency measures.

<u>Tool 1: Maps of proposals for the energy rehabilitation of buildings</u>

The databases needed to feed this Tool1 come from the annual Climate Files of Energy Plus (Energy Plus, 2023), which provide information on the climate of an area through the hourly values of the main meteorological variables

The operation of this tool requires users to first select the location of the school to identify the climatic characteristics. This placement applies to all three sections of the tool (climate maps, bioclimatic strategies, and thermal estimation). In addition, in the "Thermal Estimation" (heating and cooling) section, one more entry is required: the set temperatures. These setpoints allow you to estimate the thermal heating and cooling requirements based on the external environmental conditions.

Users of these maps can evaluate performance based on major climate trends, as well as identify the most appropriate bioclimatic measures for environmental conditions. The results obtained will allow you to self-evaluate your performance. This tool provides different analyses adapted to the locations of the schools:

"Climate Maps" section. Evaluation of the hourly distribution of the main climatic variables throughout the year using surface maps. Three main climatic variables are analyzed:

temperature, relative humidity, and global solar radiation.

- Section "Climate-adapted bioclimatic strategies". Quantification of different passive bioclimatic strategies to improve thermal comfort conditions inside schools in different climatic zones. Bioclimatic maps are defined to propose potential strategies for an optimized design based on thermal comfort conditions and local climatic conditions. These diagrams determine the comfort zone in relation to air temperature, humidity, solar radiation, and wind speed. In this methodology, the tool is applied to predict which strategies are necessary to achieve the feeling of comfort inside educational centres: increase or decrease humidity, consider natural or mechanical ventilation, solar or conventional heating, including air conditioning, giving particular importance to passive heating or cooling conditioning.

"Heating and Cooling Estimation" section. The tool conducts a qualitative study to estimate how climate influences the thermal conditioning needs of schools using the Grades Day methodology. The Heating Degrees Day (HDD) and the Cooling Degree Days (CDD) are the calculated variables that represent how fluctuations in the outside temperature affect the thermal needs of schools based on set temperatures, resulting in the "degrees hour" needed to achieve a comfortable indoor environment. Inner setpoint temperatures are initially set at 19°C and 27°C on HDD and CDD, respectively. Users can adapt these values to the needs of each school.

<u>Tool 2: Dynamic Energy Behavior of the Building</u>

This tool makes it possible to quantify the annual thermal demands of a classroom based on the climatic characteristics of the school, the position of the classroom in the building and the construction and operational characteristics. These analyses will be carried out using dynamic simulation tools, which allow the variation of the parameters (climate, construction characteristics, etc.), the input variables (setpoint temperatures, ventilation rates, etc.) and the boundary conditions (classroom position, shadows, etc.).

The location of the classroom, the construction characteristics, the shading devices, or the set temperatures selected have a significant influence on its thermal demands, the influence of which is quantified by means of a parametric study. To this end, a dynamic simulation program will be coupled with a parameterization program to generate a database that will be used as an input file in the form of a data matrix.

The methodology used to create this tool is divided into four phases. First, a representative classroom will be modelled based on climatic information, construction characteristics and operational variables. Second, different energy efficiency improvement measures will be proposed to create the tool's input simulation database. Measures such as the modification of the building's carpentry, the type of lighting, the fraction of shadow on the windows or the occupancy patterns will be studied. Thirdly, several batteries of simulations will be run to calculate the thermal loads of the representative classroom reached with the implementation of a measure. Finally, a post-processing of the outputs will be carried out to calculate the annual thermal demands and the rehabilitation savings that are achieved with each measure with respect to the initial case.

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1. <u>Identification of the current situation</u>:

Authorship, which is the basis for filling in the information requested by the tool. The teaching staff participating in the audit must create and lead an initial working group in the school, made up mainly of students from the school who then transmit the skills acquired to the rest of their classmates. Once the information has been uploaded to the application, radar graphs are obtained referring to the scores obtained based on the behavioural indicators.

2. <u>Initial evaluation of results</u>: Once the initial audit has been carried out, the users of the tool, in this case the working

group, identify those aspects in which the centre does not carry out its activity as expected, i.e. those indicators in which the score has been lower. It should be noted that obtaining a high score on an indicator does not mean that it cannot be improved, since the result produced by the application considers the situation of all the schools involved in the study.

3. Co-design of measures: Once the aspects in which to develop sustainable competencies in the school have been identified, we proceed to the proposal and design of measures to improve sustainability. This step requires a great deal of involvement from both students and teachers, as students will make proposals for activities and projects that help improve specific aspects of the school detected in the audit. Some examples of aspects that can be detected from the application are: poor management in the consumption and recycling of paper, poor waste management, insufficient management of green spaces, unsustainable transport habits or excess water consumption, among others. The main output of the design of the measures will be a project file in which the students will demonstrate that they have identified areas for improvement in the school. The duration and scope of the measures will depend on the decisions that the centre itself undertakes to take.
4. Co-implementation: This step of the methodology requires the participation of all educational levels, from the management that accepts and executes the proposed measure, to the students who will be involved in the implementation of the projects developed. In this phase, it will be demonstrated how students have been able to develop sufficient sustainability skills to identify, design and implement measures that can improve the school's performance in terms of sustainability. At the time of implementation of the measures, students, teachers, and workers must be present, such as the auxiliary staff or the school management itself, so that the students feel the support of the educational community from the beginning of the audit until the end of the measures.
5. Review and determination of the impact of the implemented measures: After leaving a reasonable amount of time in which the full implementation of the proposed measures can be carried out, an audit of the centre will be carried out again using the defined templates and tools. The participating working group of the educational centre may be made up of the same students or new ones, in the latter case maintaining contact with the previous working group. In this second audit, the cycle proposed in the methodology is closed, returning to the initial step.

In this process, the educational community will be able to identify, propose, design, implement and measure the impact of specific actions carried out in the school to improve the sustainable behaviour of the school, while improving sustainability skills at all levels of education in the school.

Despite being cyclical, it brings with it a linear growth in competencies, so that, in each completed cycle, students develop a series of skills that allow them to reproduce the cycle more efficiently, learning to identify points and quick paths for improvement more efficiently.

C. Diagnosis

The coupling of the knowledge acquired, complementing the knowledge obtained in the audit together with the tools; Some of the input information includes data from the audit itself, providing a broad and comprehensive view of both the situation of each study centre and its context, which makes it possible to make a diagnosis of its situation and recommend guidelines to be followed to improve it from an environmental and energy point of view.

The project involves 13 schools located in the 4 participating countries. These are centres that have very different characteristics from each other considering different parameters. Regarding the level of education, they range from pre-school to university education and the number of students there are institutes of 1400 students and schools of 200. The year of construction of the schools is also very different with buildings built from 1924 to 2015. The climates analysed also have very different characteristics, such as the typical Mediterranean of Seville to the subarctic of Tampere, Finland. The diagnostic methodology explained can be applied to all schools despite their differences; and make changes that are evaluated throughout the project.

III. Results

In this article, CEIP Mozart is selected as a demonstration case. This educational centre is in Alcalá de Henares, a city located northeast of Madrid in Spain, characterized by a continental Mediterranean climate. The CEIP complex built in 2007 occupies a plot of approximately 11000 m2.

Currently in the 2022/2023 school year there are 700 students enrolled in the school, and fifty people working in the centre (teachers, administration, maintenance, and cleaning of the building).

A. Audit

In a previous audit, the following information and documentation is obtained: electricity bills, gas bills (discriminating between heating and cooking use), publicly accessible files (Cadastre, Public Services Platform for the Educational Community of the Community of Madrid, school website, aerial photographs), original design plans available at the Department of Education (design of the heating and

Fig. 7. CEIP Mozart

plumbing system; design of the electrical system and lighting, materials used in construction, etc.). A starting point is defined in the understanding of the building's use, energy consumption and carbon footprint of the school.

There are three visits:

- An initial introduction, where the school staff introduces the building and the context, describes its current situation, particularly in aspects related to sustainability.
- A second visit, carried out at the time when the main templates are available, filled in at many points with the help of the centre's staff. In it, additional doubts are clarified, photographs are taken, the material under consideration is checked, strengths and weaknesses are checked in situ, and new ones are located; and finally, classes of interest are pre-selected for monitoring.
- A third focused on studying the electrical installation to design the monitoring system.

Among the information acquired, a series of points related to the energy audit stand out:

- The thermal and electrical demands of the main building and gymnasium are supplied with natural gas and electricity equipment. However, there is no refrigeration equipment.
- Electricity consumption is mainly due to the lighting consumption of the entire school and gymnasium, as well as some equipment installed in the kitchen (irons, refrigeration, air extraction), some equipment in the classrooms (computers, projectors, digital screens, tablets), photocopiers and laminators.
- The priority lighting systems are fluorescent lamps installed as rectangular luminaires that fit into a grid of the modular false ceiling. Lighting is turned on on demand. The light installation is approximately 60 kW. The light bulbs in the initial installation are not energy-efficient.
- The consumption of natural gas is mainly intended to cover heating and hot water demands. For this purpose, a 400-kW central boiler of the Adisa DUPLEX EVO brand is available
- In classrooms, heating distribution systems are radiator systems located under windows
- The building is of recent construction, with a design just prior to the implementation of a more restrictive technical building code, affecting its energy demand values.
- The annual electricity consumption recorded since 2015 is very regular, with the exceptions of 2020 and 2021 due to measures against Covid-19.
- The consumption of gas in heating has a profile appropriate to the season of the year. Between May and September there is no consumption.
- There is currently no renewable energy technology installed.
- The windows have manual opening for cross ventilation. They are a point of heat loss.
- The awnings installed on the south-facing windows are very deteriorated
- The playground where recess is held is almost entirely uncovered.
- The centre participates in several environmental programmes and initiatives, related to sustainability, environmental issues, waste reduction and recycling, the local economy, and the restoration of ecosystems. It is very aware of the points analysed in the audit and it is easy to obtain the information.
- A week-long campaign for waste measures is carried out
- Public bus stops and lines are identified in two proximity radii. The Transport Uses Survey is carried out.
- The information obtained allows us to obtain a high percentage of the defined KPIs, although those related to air quality have not yet been obtained.
- By analysing the electrical panels and the selected classrooms, a monitoring system has been designed for two classrooms – one for primary school and the other for infants, in different areas and orientations of the building. A three-phase meter is used to measure lighting, a single-phase meter to measure force, a multi-sensor meter for indoor conditions, and a minicomputer in each classroom to manage the data and store it on a web server; From where teachers and students will be able to access it to view it, and researchers to analyse it.

B. *Application of the tools*

The application of the environmental impact calculation tool, currently in Excel format (ECF4CLIM-A, 2023) has been carried out using the online questionnaire and audits. For the present diagnosis, the household footprint part has not been used since it is focused on the individual personal use of the users. The tool allows you to calculate the footprint without having to fill in the total data, so the final scope is determined

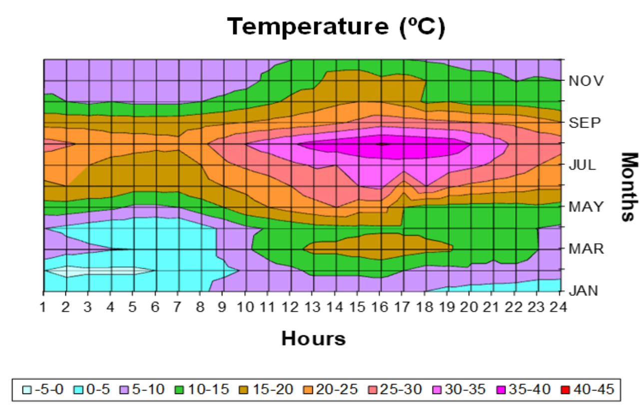


Fig. 8. Surface temperature map for CEIP Mozart.

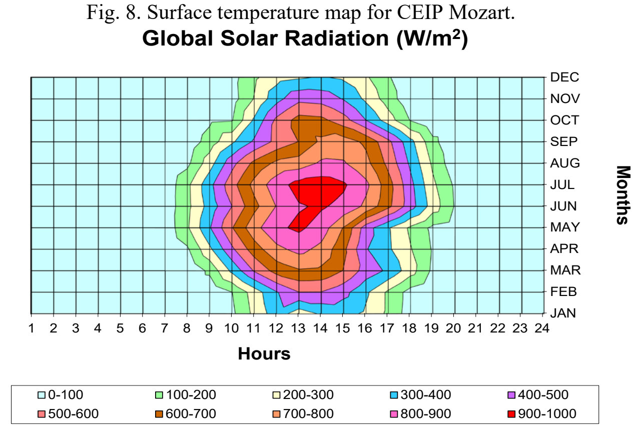


Fig. 9: Global Solar Radiation Surface Map for CEIP Mozart.

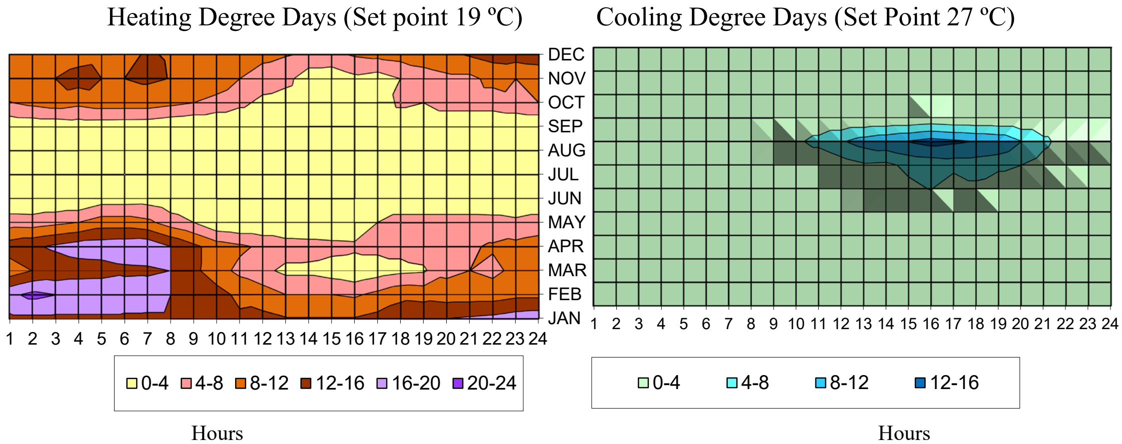


Fig. 10. Surface Maps of Estimation of Heating and Cooling Demands for CEIP Mozart.

by availability. In this case, the data have been completed to a high degree in the absence of: transport for excursions and consumption of the centre in didactic and administrative material.

The application of the Energy Rehabilitation Toolkit (Tool 1) on the CEIP Mozart provides climate maps and estimation maps of the heating and cooling needs required to achieve the thermal comfort setpoints (established according to Spanish national regulations: 19°C in winter and 27°C in summer). Figures 8 and 9 show the profiles of outdoor air temperature and global solar radiation as a function of the time of day and months of the year.

Once the heating and cooling setpoints have been set at 19°C and 27°C respectively, the thermal demands of the CEIP Mozart are estimated based on climatic values. Figure 10 shows the estimated degree days of heating during the winter (left chart) and the degrees days of cooling during the summer (right chart).

Three types of windows have been analysed according to the year of construction of the building. These windows are characterized by the type of glass and frame that compose it according to CTE. (Technical Building Code, 2006; 2013).

Based on the definition of the conditioning periods of the CTE, two annual periods are identified to model the air conditioning: summer and winter, establishing, for each of them, a temperature setpoint. Internal loads are defined by their occupancy values, lighting, and equipment. In this typology, a differentiation is made in the occupation between working days and holidays.

Two types of air changes have been modeled: ventilation and infiltration. Basic ventilation is taken independently of infiltration and is carried out according to occupancy (1.2 ren/h with occupancy vs. 0.2 ren/h without occupancy). No type of natural or forced ventilation is simulated in summer. On the other hand, a constant infiltration value is chosen, which varies according to the year of construction and the type of building, as shown in Table 3.

Different percentages of shading have been defined on the windows in each of the main orientations (north, south, east, and west). The percentages analysed for each orientation are: 0.25, 0.50, 0.75 and 0.1.

C. *Diagnosis*

The audit identifies that the school maintains good habits, has some vulnerable points energetically related to construction and facilities, which will allow improvement interventions to be carried out. Sliding windows in classrooms are a point of heat loss. The awnings in the south-facing classrooms are in very poor condition, limiting their protection capacity in periods close to summer. The lighting installation can be optimised by replacing the current bulbs with energy-saving ones, with the consequent energy savings. These three points are the most striking.

TABLE I
LIMIT VALUES OF THE OVERALL LOSS COEFFICIENT OF EACH ENCLOSURE IN THE THREE REGULATORY RANGES AND FOR CLIMATE ZONE D3.

Construction walls	NBE-CT79	CTE 2006	CTE 2013
Cover	0.90	0.38	0.22
Façade wall	1.40	0.66	0.27
Solera	1.00	0.66	0.27
Vertical Interior Partition	1.44	0.66	0.66
Forged	0.96	0.38	0.38

TABLE II
GLAZING CHARACTERISTICS

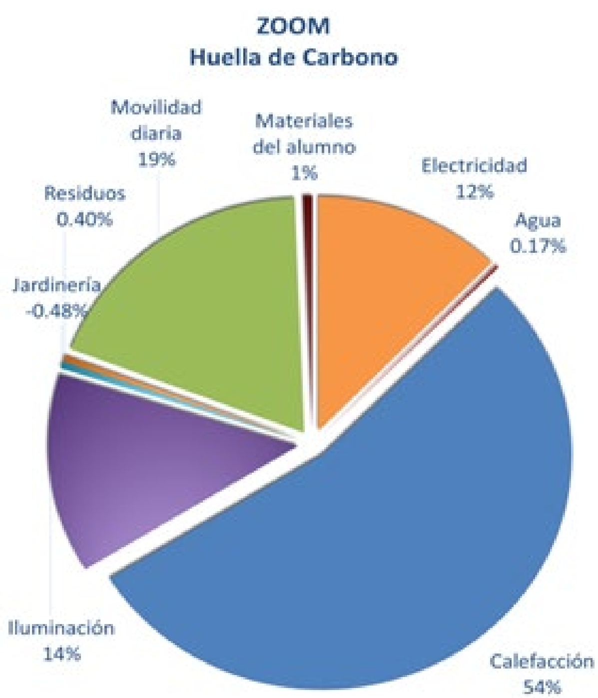
Glazing type	A (W/m^2K)	g (-)	Frame Type	A (W/m^2K)
Double	3.25	0.76	Metallic with RTP	4.0
Double Low Emissive I	1.54	0.65	Wood/PVC	2.2
Double Low Emissive II	0.97	0.61	Wood/PVC	2.2

TABLE III
INFILTRATION VALUES

Infiltrations (ren/h)		
Building	**NBE-CT79**	**CTE 2006-CTE 2013**
Family	0.8	0.3
Block	0.8	0.24

		Total CENTRO EDUCATIVO Y AÑO	Por ESTUDIANTE Y AÑO			
			Gestión de Centro	Actividades de aprendizaje	Movilidad	Total
Global impacts	Climate change (kg CO2 eq)	131715.3	153.9	5.5	35.8	**190.8**
	Ozone depletion (kg CFC-11 eq)	0.0	2.17E-05	3.75E-07	5.42E-06	**2.72E-05**
Human Health	Human toxicity, non-cancer effects (CTUh)	0.0	9.58E-06	1.76E-06	2.41E-06	**1.23E-05**
	Human toxicity, cancer effects CTUh	0.0	2.21E-06	3.66E-07	5.95E-08	**2.34E-06**
	Particulate matter (kg PM2.5 eq)	42.2	4.80E-02	8.24E-03	6.33E-03	**5.59E-02**
	Photochemical ozone formation (kg NMVOC eq)	233.4	2.32E-01	1.69E-02	9.69E-02	**3.32E-01**
Ecosystems Damage	Acidification (mol H+ eq)	299.0	3.28E-01	3.62E-02	7.91E-02	**4.14E-01**
	Freshwater eutrophication (kg P eq)	7.6	8.33E-03	2.37E-03	5.82E-04	**9.34E-03**
	Freshwater ecotoxicity (CTUe)	79122.2	60.6	43.4	13.1	**81.4**
Resources Depletion	Land use (kg deficit de C)	48480.5	61.8	10.0	0.0	**64.5**
	Water resource depletion (m3 water eq)	2420.3	3.5	0.1	0.0	**3.5**
	Mineral, fossil & ren resource depletion (kg Sb eq)	5.0	0.01	0.00	0.00	**0.01**

Fig. 11 (a)



(b)

Fig. 11: Results of the Environmental Footprint Calculator applied to CEIP Mozart (a) and contribution to the Carbon Footprint of the activities (b).

The application of the Environmental Footprint Calculator shows the results in terms of impacts by subsystem for the entire school system and by student and year (Figure 11-a). In the case of the school evaluated, it is observed that the management of the school and transport are responsible for most of the impacts in almost all categories. These are trends already observed in other similar centres. In addition, detailed results can be obtained from the activities involved in each of the subsystems, and the impact can be broken down by contributions. In this way, improvement actions can be identified to, on the one hand, reduce the direct impact of the school, and, on the other, the impacts associated with the production of the materials and resources needed in the educational activity. Figure 11-b zooms in on the contributions to the Carbon Footprint (Climate Change, kg of CO2 eq.). These results are in line with those previously found in the evaluation of the environmental footprint of students from other schools in Spain and Portugal (Lizana et al., 2021).

Analysing the Surface Map of Outside Air Temperature for the CEIP Mozart, the warmest period of the year occurs during the months of July and August (non-school months), while in June and September the temperature exceeds 27°C from 1pm and 4pm respectively. This period is the one that corresponds to the highest incidence of solar radiation, so it is very likely necessary to include effective shade elements in the classrooms. In winter, the outdoor values are quite cold, registering values below 19°C for most of the winter hours. At this time of year, the aim is to maximise the incidence of solar radiation on the classrooms, increasing heat gains in a natural way. Spring and autumn are milder seasons, reaching exterior values within the bands established in the comfort instructions throughout a good part of the school day. However, this period also registers high values of solar radiation, so it may be necessary to have a solar control system when temperatures are high.

When reviewing the demand estimation maps, the main heating demands occur in the most severe winter months until 8 or 9 a.m. and from 9 p.m. On the contrary, the highest cooling needs occur from 12 noon in the summer months.

IV. Conclusions

The project ECF4CLIM equips European schools with skills for the transition to a climate-neutral economy in Europe.

The design of a methodology for the diagnosis of educational centres makes it possible to obtain information aimed at the energy and environmental analysis of each participating centre, easy to understand by technical and educational staff, aimed at improving the operation of the centre as well as generating knowledge and learning. To this end, an audit is combined with which different sections related to the sustainability of each centre are assessed in a quantitative and comparable way, such as consumption in air conditioning, transport, water management or waste. The tools help to interpret the results of the audit, while allowing them to be applied to have a better understanding of the context of the building, its location, the habits that are held and their consequences; as well as the possibilities of action, such as changes in infrastructures, consumption of goods or habits, with which to increase the efficiency of the centre, reduce its consumption of electricity and air conditioning, mitigate the carbon footprint and pollution generated.

The diagnosis applied to CEIP Mozart allows an assessment of this educational centre within the framework of the project during its first months, to determine its current state and to locate the points that produce the greatest environmental impact and energy consumption, which can be improved during the development of ECF4CLIM. The audit obtains quality data with which the tools developed are fed, and together they locate the most polluting processes, the effect of the local climate, and begin to analyze the effect of the architectural design, directing this information to possible interventions, whose effect will be assessed later.

Identifying needs and common challenges is critical to guide action strategies towards decarbonisation and achieving higher levels of sustainability in the education sector at all scales.

References

Banco Mundial. https://datos.bancomundial.org/indicador/SP.POP.TOTL (accedido el 17/03/2023).

ClimACT project. Transition to a low carbon economy in schools. https:// http://www.climact.net/ (accedido el 17/03/2023).

Código Técnico de la Edificación (CTE) Documento Básico de Ahorro de Energía (DB-HE). https://www.codigotecnico.org/DocumentosCTE/DocumentosCTE.html (accedido el 17/03/2023).

Digital Platform. ECF4CLIM-A European competence framework for a low carbon economy and sustainability through education: https://ecf4clim.smartwatt.net/simulators-space/simulators-space.html#environmental (accedido el 17/03/2023).

ECF4CLIM-A European competence framework for a low carbon economy and sustainability through education. https://www.ecf4clim.net/ (accedido el 17/03/2023).

EnergyPlus™. Computer software. Version 00. September 30, 2017. https://www.osti.gov//servlets/purl/1395882 (accedido el 17/03/2023).

European Commission - Joint Research Centre. 2011. International Reference Life Cycle Data System (ILCD) Handbook Recommendations for Life Cycle Impact Assessment in the European context. First edition November 2011. EUR 24571 EN. Luxemburg. Publications Office of the European Union; 2011.

European Environment Agency (2021). Total greenhouse gas emission trends and projections in Europe. https://www.eea.europa.eu/ims/total-greenhouse-gas-emission-trends (accedido el 17/03/2023).

Eurostat - high-quality statistics and data on Europe https://ec.europa.eu/eurostat/statistics-explained/index.php (accedido el 17/03/2023).

IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844. [Gamarra A. et al. (2021) Low-Carbon Economy in Schools: Environmental Footprint and Associated Externalities of Five Schools in Southwestern Europe. Energies 14(19), 6238.

A.R. Gamarra, I.R. Istrate, I. Herrera, C. Lago, J. Lizana, Y. Lechón. Energy and water consumption and carbon footprint of school buildings in hot climate conditions. Results from life cycle assessment, Journal of Cleaner Production, Vol. 195, (2018) 1326-1337, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.05.153

A.R. Gamarra, I. Herrera, Y. Lechón, Assessing sustainability performance in the educational sector. A high school case study, STOTEN, Vol. 692 (2019) Pag.465-478, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2019.07.264

Lizana J. et al. (2021) A methodology to empower citizens towards a low-carbon economy. The potential of schools and sustainability indicators Development of integrated demand and supply side management. J. Environ. Manage. 284, 112043.