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Energy Intervention Model in Public Education Institutions that Contribute to Sustainable Development

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ABSTRACT

Sustainable development is a global policy that requires the collective effort of the actors present in each territory. In this sense, an energy renewal intervention model is presented at the Juan XXIII Educational Institution in the city of Monteria, Córdoba, Colombia, which results from alliances between international, national, and regional actors, becoming a reference that could serve as a basis. To be replicated in other institutions with characteristics similar to those described in this case. The model generally describes the entire process carried out in the intervention and focuses on the benefits generated for the educational community. Among the main results, the increase in thermal, lighting, and acoustic comfort of the educational community stands out, according to a survey and semi-structured interviews carried out. A fact that could be attributed to the perception of increased comfort in the community is the increase in the student population in 2022, going from 1,478 in 2019 to 1,909 in 2022, with a growth of approximately 29%. Energy renovation also resulted in the improvement of the indoor climate of the classrooms (from 35°C to 27°C), the improvement in the physical infrastructure of the institution, the integration of photovoltaic solar energy, and the subsequent reduction of energy cost.

INTRODUCTION

In the city of Monteria, a city located in the Department of Córdoba in Colombia, temperatures in classrooms are higher than 35 degrees Celsius during the day. In addition, the percentage of humidity can vary between 60 and 80. The conditions of confinement due to the use of poorly ventilated classrooms result in a lack of fresh air and high concentrations of CO_2. According to the study done in Australia by Rajagopalan et al. 2022, Children under 15 years of age spend more than six hours a day in school buildings. They are particularly vulnerable to the effects of poor indoor air quality (IAQ). As expressed by Bogdanovica et al. (2020), indoor air quality (IAQ) can be characterized by several metrics, such as the level of pollutants, humidity, temperature, etc. Indoor carbon dioxide concentration is one of the most important indices of IAQ due to its ability to affect the human body. Carbon dioxide concentrations in the air at 1000 ppm can cause poisoning and have been shown to affect the human thought process. Likewise, Johnson et al. (2018) mention that associations have been demonstrated between poor indoor air quality (IAQ) in the classroom and the risk of asthma in schoolchildren, increased absenteeism, and poor performance on standardized tests. According to Bartyzel et al. (2020), intensive ventilation is the only way to remove excess CO_2 from indoors.

As expressed by Almeida et al. (2017), knowing that children spend much of their time inside school buildings, and they are more susceptible than adults to the adverse effects of indoor pollutants of their relationship with the volume of air breathed. The weight is greater and their tissues and organs are still growing. The construction and rehabilitation of school buildings must be properly planned to ensure that users have the appropriate conditions to do their work. As noted by Andamon et al. (2023), inadequate ventilation and occupant density in school classrooms result in indoor air quality exceeding the criteria of current standards. According to Chen et al. (2022), Adequate classroom air quality is vital to student health and learning outcomes.

Internal thermal comfort in hot and humid climates is extremely important for schools since inadequate comfort conditions make it difficult for students to concentrate and perform at school. Many Educational Institutions (EI) have an energy-inefficient infrastructure and Juan XXIII was no exception. An example of this was the lack of thermal insulation and airtightness, as well as the installation of inefficient lighting fixtures. This EI, like others, also suffered from high energy costs. According to Elnabawi & Saber (2022), the high amount of energy used, in addition to its quality, is putting greater pressure on the surrounding environment by increasing the intensity of carbon emissions (CO_2) from the construction sector, which increases indoor and outdoor air pollution levels, generating an impact on health risk, energy insecurity, and climate change.

Since the United Nations (UN) declaration of the objectives of sustainable development, territorial dynamics have been generated at all levels aimed at the implementation of actions to achieve sustainability. As Matthey-Junod et al. (2022) point out, sustainable energy access interventions are often associated with both economic growth and social development. Affordable, sustainable, reliable, and modern energy, the focus of Sustainable Development Goal 7 (SDG 7), can act as an "engine" to directly influence productivity, income, and health and can promote gender equality, education, and access to other infrastructure services. One of these actions took place in the city of Monteria in response to the problems described in the city's public education institutions and was implemented at the Juan XXIII EI. The entire process arose from the approach of the "Energy Efficient City" management tool of Swiss origin, with a history of 25 years. The Initiative originated in 2018 and to date presents results at a social, environmental, and economic level. To achieve the results and as part of the "Energy Efficient City" approach, the articulation of actions of international entities was necessary, such as the Embassy of Switzerland-State Secretariat for Economic Affairs (SECO); national entities, such as the Mining-Energy Planning Unit (UPME), an entity attached to the Ministry of Mines and Energy of Colombia and the Corporation for Energy and the Environment - CORPOEMA – as well as regional institutions, such as Monteria Mayor's Office.

The Energy Efficient City tool involves municipalities in a continuous process of local energy planning, management, and monitoring aimed at a progressive improvement of local energy performance. This process involves the municipality, its administration, and its elected representatives, as well as a multitude of local partners, including the public, private, academic, and association sectors. The objective is to promote concrete actions and provide local governments and their partners with the means to carry out an integrated, participatory, and sustainable energy policy.

As noted by Rosbach et al. (2013), classroom ventilation was already recognized as an important determinant of indoor air quality at the beginning of the 20th century. According to Dovjak et al. (2020), air pollution in closed spaces can have an impact on the health of students. Likewise, Liébana (2021) mentioned the impact of the real estate stock on energy consumption and environmental pollution in Europe, leading to the development of an instrument that allows classifying the buildings of educational institutions. Thus, analyzing the current state and planning an energy renewal. As expressed by (Mombeuil, 2020) modern societies have realized that their strong dependence on conventional energies has resulted in serious environmental problems, being pollution, climate change, and deforestation being the most cited examples. Additionally, Cabello et al. (2019) evaluated the energy potential of the Colombian Caribbean Coast, corroborating the viability of renewable energy projects in the reconditioning of buildings in cities with warm climates like the city of Monteria.

Based on what was stated in previous studies, energy renewal processes in educational institutions are relevant since the conditions of the spaces in which training activities are carried out have an impact on the health and performance of the community, which suggests a responsibility of the competent authorities regarding variables associated with the comfort of individuals in these spaces. On the other hand, as expressed by Ferrer-Estévez & Chalmeta (2021), humanity is beginning to become aware of the limits of the planet and the unsustainability of its development, which has led to the current state of global emergency. The conditions of the buildings also affect environmental pollution, generating economic and environmental extra costs that can be considerably reduced by carrying out renovation processes in the buildings. Finally, there are many territories that, as in the case of Monteria, have privileged energy potentials to be used that can contribute not only to the health and performance of the educational community but also to the reduction of the impact on the environment and the economy of the institutions.

The scenario described served as a platform for the convergence of actors with common interests in sustainable development, specific according to their mission and vision. This allowed the transfer of knowledge of the actors and the development of the project entitled "*Energy renovation of the Juan xxiii educational institution, in the municipality of Montería, department of Córdoba*". This work presents the methodology that guided the development of the project and the main findings resulting from measurements of conditions in the spaces of the intervention and the perceptions of those who benefited from it. The project itself is presented as a model of energy efficiency intervention in territories and institutions with similar characteristics, which allows for the transfer of knowledge and the improvement of the methodology based on the lessons learned.

MATERIALS AND METHODS

The development of the project was carried out with a mixed approach with an exploratory and descriptive scope. The population was the educational community of the Juan XXIII EI with the participation of administrative staff, teachers, students, and parents. As measurement instruments, specialized equipment was used to take readings of the intervened comfort variables, perception surveys, and semi-structured interviews with administrative staff, teachers, and students. For the development of the intervention, as previously mentioned, the Energy Efficient Cities approach was followed; in this way, the entire process is presented below from the perspective of a model for energy management supported by the total quality cycle known as PHVA (Spanish for Plan, Do, Validate, and Act). This cycle allows an energy renewal project to be seen as a management process, in which we start from an initial state and generate actions to advance over time towards environmentally friendly systems that benefit not only health but also the environment and the economy of the EI. Fig. 1 shows the phases followed in the intervention.

Regarding the development of the quantitative study, pieces of equipment were installed to measure temperature, relative humidity (RH), and carbon dioxide that was present in three different places in the EI, which correspond to the three types of interventions implemented. The measurements were taken before and after the interventions at different time ranges.

In addition, the EI's Academic Coordinator carried out a perception survey with parents, teachers, administrators, and students through the communication channels enabled for the educational community during the pandemic. The survey investigated the perception of community members regarding thermal, lighting, and acoustic comfort. Interviews were also conducted with students, teachers, and administrators to collect information related to positive aspects of the intervention and aspects that should be improved.

RESULTS AND DISCUSSION

After implementing the strategies proposed by the methodology in this study, it was possible to obtain three types of results. The first of them constitutes a model for the energy renewal of the EI, the model is established by phases that adjust to the PHVA cycle for continuous improvement. The second result corresponds to the contrast between before-and-after variables such as temperature to establish the differences gained from the intervention. The third result is the perception of comfort obtained from the opinions of the community regarding comfort variables, positive aspects, and improvements in EI after the intervention is completed.

Model for Energy Renewal in an EI With a Hot Humid Climate

The model is made up of 4 stages that mark the beginning and continuation of a project that seeks the energy renewal of an institution and plans its operation by the incorporation of renewable energies.

Planning Stage

Commit to the SGEn: As a product of a collaboration

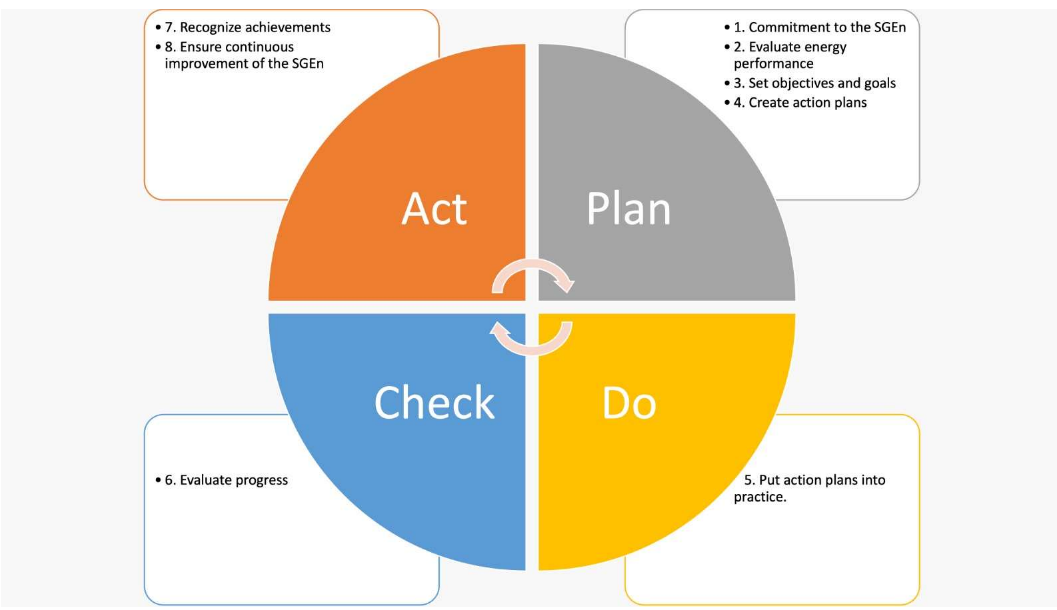


Fig. 1: Phases of the energy intervention model at the Juan XXIII Educational Institution under the approach of Energy Efficient Cities.

between the Embassy of Switzerland-State Secretariat for Economic Affairs (SECO), the Mining-Energy Planning Unit (UPME), the Corporation for Energy and the Environment - CORPOEMA- and the mayor's office of Monteria, and given the interest in the benefits of implementing the plan, the Energy Efficient City Initiative was created (www.ciudadenergetica.co).

The Initiative had a pilot phase for 3 years, with Monteria being one of the pilot cities. The energy renovation of the Juan XXIII Educational Institution is one of the flagship projects of the Local Energy Strategy that was developed for Monteria within the framework of a multi-actor participatory process. This project was born as a response to the poor living conditions in the classrooms, associated with the high concentration of students, the harshness of the subtropical climate, and a design without basic concepts of bioclimatic architecture. The challenge was to improve the conditions of the indoor environment where the students worked through the implementation of active and passive measures, with a controlled increase in the school's operational expenses. On the other hand, it is known that school performance can improve when adequate temperature conditions exist (Wargocki & Wyon 2006).

Evaluate energy performance: In this phase, the conditions of the EI are evaluated to establish goals and objectives. Table 1 presents some general aspects of the EI.

From the characterization of the EI, it was possible to identify problems that could be improved; these are presented in Table 2.

Establish goals and objectives: In the case of Juan XXIII school, three types of intervention strategies were defined to improve the quality of the interior environment of the classrooms. The objective was to reduce the budget and be able to compare different models. The goals were established based on the desired comfort situation (See Table 2)

Table 1: General parameters of the project.

Characteristic	Initial state
Age of buildings	Between 10 and 20 years
Constructed area	1.840 m^2
Land area	3.806 m^2
Number of students	1.023
Educational stages	Primary and secondary
Number of classrooms	14 out of 23 are not air-conditioned
Wall material	Cement bricks
Roof material	Zinc sheets
Windows	Flat glass in air-conditioned rooms Cement brick or metallic grid in non-air-conditioned rooms
Air conditioning systems	Split Systems
Lightning	T8 Fluorescent Tube T10 Fluorescent Tube Compact fluorescent lightbulbs

Create action plans: Based on the identified problems and the defined objective, progress was made toward specifying the actions that could be carried out to address them (Table 3).

Doing stage: Once the goals and objectives of the project were established, the bidding and contracting process of the companies in charge of implementing the project and the corresponding auditing began. The company SERVICIOS Y OPERACIONES S.A.S ("Contractor") had the purpose of "ENERGY RENOVATION OF THE JUAN XXIII EDUCATIONAL INSTITUTION IN THE MUNICIPALITY OF MONTERÍA, DEPARTMENT OF CÓRDOBA" and N&S CONSTRUCCIONES S.A.S acted as auditor of the project.

Implement the action plans: Following the proposed lines, the action plan included three types of interventions:

- **Type 1: Complete intervention.** It was applied in those areas where the worst environmental conditions existed inside. This solution is the one that allows better thermal comfort but may have higher investment and operation costs.
- **Type 2: Medium intervention.** It was mainly applied in classrooms located on the first floors since, unlike the second floors, they do not have a roof surface directly exposed to the sun. It is possible to adapt later into a complete intervention.
- **Type 3: Insulation only.** It was applied exclusively in a building that had an architectural design suitable for warm areas. It had enough roof height, allowing better natural ventilation.

Table 4 presents the measures applied and the type of intervention carried out.

Evaluating Stage

Evaluate progress: To evaluate progress, a detailed schedule was established by stages with activities and results to be verified. The entire process was carried out by the auditor who supervised the progress of the works defined in the project. Table 5 shows the main results that were used as a basis for the evaluation of the results. Likewise, in the results part, the evidence obtained from the application of the evaluation instruments will be provided.

Acting Stage

Recognize achievements: The benefits of the interventions have an impact on the three pillars of sustainability: society, the environment, and the economy. Among the main benefits

Table 2: Description of main issues.

Problem	EI situation 2. Energy performance evaluation	Expected situation: students' comfort and safety. 3. Goals and objectives
(1) High temperatures inside the classrooms	Between 34 and 38ºC (*Measurements taken in a room with two air conditioners and several ceiling fans*)	Between 25 and 27ºC
(2) High temperatures outside the building	Roof temperature: 70°C Outer wall temperature: 40°C (*Measurements taken with thermal imaging camera*)	Reduction of solar radiation on walls and roofs. Lower the temperature of walls and roofs. Reduction of heat radiation from walls and roofs into the classroom
(3) High levels of relative humidity in the classrooms	Between 60% and 80% (*Monitoring carried out for several days in a classroom with air conditioning equipment and ceiling fans*)	Between 40% and 60%, along with an adequate temperature
(4) Very poor air quality	The CO_2 concentration of the air inside the classrooms: up to 3'000 parts per million (ppm) Outdoor air reference: between 350 and 400 ppm (*Measurements taken in an air-conditioned room*)	The CO_2 concentration of the air inside the classrooms below 1'000 ppm (According to international recommendations of ASHRAE 62.1, with ventilation of 13 $m^{-3}.h^{-1}$ per student in each classroom)
(5) High energy consumption and associated costs	Rise of energy consumption after the installation of air conditioning equipment and ceiling fans (*monthly electricity bill: ~6MM COP*)	Reduction of the monthly electricity bill: at least 20%
(6) Lack of knowledge of the school's energy behavior	There is no energy monitoring, and the behavior of the different energy-consuming systems is not known. The school neither receives electricity bills nor does it pay them directly (the Secretary of Education does so). There is not enough information for taking measurements to reduce energy consumption.	There is monitoring of the main energy-consuming equipment. Consequence: misuse or malfunctions can be identified, and energy consumption controlled.
(7) Poor lightning	Curtains, cloths, or plastic on the windows Artificial lighting in classrooms is below the values recommended by Colombian regulations. Dark spaces that are not suitable for studying	Control of direct solar radiation by construction elements Artificial lighting according to the Technical Regulations for Lighting and Public Lighting RETILAP Standardized lighting levels
(8) Recreation áreas barely used	Recreation areas (e.g., courts, patios, etc.) are exposed to high levels of solar radiation. Little use of the courts. Concrete or cement slabs emitting heat due to incident radiation	Shaded recreation areas. Use of courts during regular school days and off school hours (by students and community)
(9) Malfunction of air conditioning equipment	The equipment works using air at 16ºC and the maximum air speed without being able to sufficiently lower the temperatures in the classrooms.	Air conditioning is configured to maintain classrooms at an ambient temperature between 25 and 27°C.
(10) Uneven distribution of temperatures within classrooms	Very cold high-velocity stream near air conditioning equipment Students located far from air conditioning do not perceive the sensation of cooling. Direct solar radiation to students located near the window	Air conditioning equipment with better temperature distribution inside the classroom Control of direct solar radiation by constructive elements
(11) Non-compliance with electrical regulations	Non-compliance with the Technical Regulations for Electrical Installations (RETIE) due to the age of the facilities. The modifications to the electrical system over time were carried out according to standards, and consent for the construction improvement was recorded. Risk situation for users Impossibility of modifying the school's electrical system (e.g., the installation of photovoltaic panels) without complying with the regulations	Rise and improvement of security conditions for users
(12) Non-compliance with structural roof regulations	Non-compliance with the regulations of some structural elements due to age Safety risks for those who will work on the construction site. Risk of damaging roofs during work	Structural reinforcements when necessary to allow the development of roofing work. Compliance with regulations on roofs Compliance with the manufacturer's recommendations for installing tiles

identified in the intervention of the Juan XXIII EI and that have a high level of replicability in other EI, we can mention:

Social: Improvement of environmental comfort and health of students. With the energy renovation of the school, the temperature and humidity of the classrooms are controlled and maintained within comfort limits. This has a direct impact on overall school performance.

Improvement of school performance. An appropriate

Table 4: Matrix of measures applied to each type of intervention.

Applied measures	Type 1: complete intervention	Type 2: semi-complete intervention	Type 3: insulation only
Outer walls insulation	x	x	x
Roof and ceiling insulation	x		x
Removal of ceilings in rooms without air conditioning		x	
Window eaves		x	x
Improvement of the quality of windows and the airtightness of the enclosure	x	x	
Efficient air conditioning with centralized control	x		
Mechanic ventilation	x		
Efficient ceiling fans		x	
LED lighting	x		x
Ceiling ventilation	x		
Photovoltaic system	x	x	x
Outdoor shaded areas	x	x	x
Vegetation areas	x	x	x

Table 5: Planification stages and expected results.

Stage	Phase	Activities	Results
Planning	Initial studies	• Definition of goals: • Objectives, scope, and project management • Participatory Consultation / Workshop • Elaboration of the energy renewal concept: • Preliminary data collection and analysis • Definition of the current state of the building (energy consumption, operating costs, structural and electrical status, etc.)	√ General objectives and scope of the project √ Team organization chart with assigned responsibilities √ First project calendar √ Basic status report of the school (structure, electrical system) √ Energy renewal concept
	Engineering	• Elaboration of the energy renewal concept or basic engineering, including the measure. Elements and the action plan proposed. • Validation of the budget and the measures to be implemented. • Engineering details design with plans • Definition of the bidding type	√ Basic engineering plans and calculations √ Feasibility study with approximate costs and prioritization of measurements √ Definition of parameters to be monitored. √ Selection of measurements to be implemented. √ Updated project calendar √ Detailed engineering, including plans and calculation reports of the measurements being implemented
	Bidding	• Writing the technical and administrative specifications, defining the minimum requirements for selecting the company • Work schedule • License and permit processing • Bidding publication • Field trip with candidates • Drafting and signing of the contract • Writing and signing of the contract • Bidding and hiring of the auditing company	√ Detailed engineering plans √ Bidding documents (including work schedule) √ Final Budget assignment (and reserve budget) √ Construction license √ Electrical permits √ Signed contract of the construction company √ Auditing company with a signed contract

Table Cont....

Stage	Phase	Activities	Results
Execution	Construction and approval	• Monitoring of the execution of the project and quality control • Adaptation of the measurements for possible unforeseen events that may arise on-site. • Implementation and trials/testing to ensure proper functioning and execution of the measurements (including any corrective actions)	√ Work monitoring reports (including quality control) √ Start-up report with the measurements carried out, their results, the corrective measures to be taken, responsible staff, and the execution date. √ Operation and maintenance booklets of the intervened aspects √ Signed maintenance contracts. √ Monitoring criterion defined. √ Work reception form √ Opening ceremony
Operation	Maintenance	• Adjustment of optimal parameters for operating and maintenance • Training and education of responsible staff for operation, maintenance, data collecting, and information monitoring. • Optimization and repairment of flaws prior to final delivery • Frequent control and maintenance according to the booklet.	√ Building working under normal conditions √ Annual monitoring reports √ Maintenance reports

work environment (controlled temperature, humidity, and noise) allows students to use their attention span and retention capacity to the fullest.

It becomes a pivotal place for the community. Once renovated and equipped, the EI has been used for community meetings, fostering the link between the community and the EI. This is particularly important in vulnerable or low-income neighborhoods.

Environmental: Environmental education program. Students can take advantage of the measures implemented to study the avoided environmental impacts and understand processes based on renewable energy or see how energy efficiency measures impact. These themes could be tangible for them.

Use of local renewable resources. An energy renewal project can incorporate an energy generation component based on renewable resources; typically, photovoltaic systems are connected to the grid for the generation of electrical energy. In this way, they will participate in the diversification of the country's energy matrix and increase its supply security.

Reduction of greenhouse gas emissions. The measures implemented for energy efficiency and the use of clean energy, in addition to improving the comfort of students, are interventions that contribute to the reduction of greenhouse gas emissions. This reduction in emissions is estimated at 59 tCO_2 per year in the case of the Juan XXIII EI. The cost of avoiding the emission of one tCO_2 is estimated at 28 USD. A positive outcome is compliance with international climate change mitigation goals from Colombia.

Economic: Reduction of operating costs. By prioritizing passive solutions (e.g., improving the enclosure, roofed patios, green areas, etc.) to improve the environment in classrooms, the use of air conditioning equipment can be reduced and optimized. This had a reduction effect on electricity costs for the school.

Improving the reputation of the school. Schools, where energy renovations are implemented, demonstrate a willingness to innovate and are in sync with the environmental and educational concerns of the moment. This is a component that contributes to its institutional image as an educational establishment. This caused an approximate increase of 29% in the demand for openings in 2022.

Infrastructure: Increase in structural safety. This is a non-quantifiable benefit but corresponds to the improvement of the building's infrastructure to receive the energy interventions. In the case of the intervention of Juan XXIII EI, it included the improvement in the roof of the support straps of the tiles, the placement of columns in the perimeter walls to provide greater stability, and the placement of reinforcements in some walls that presented cracks or other structural problems.

Increase in electrical safety: For the installation of photovoltaic and air conditioning systems, as well as all general electrical installations, it was required to comply with current electrical regulations. This compliance cost does not present an economic return, but it must be considered when executing this type of project since, in general, the EI does not have a safe electrical infrastructure, and the safety of the entire community is put at risk.

Ensure continuous improvement of the SGEn: To ensure the continuous improvement of the project, certain conditions must be met from the beginning at the level of the process, financing, communication, and community participation. Additionally, actions necessary for the correct use, maintenance, and improvement of the infrastructure and conditions generated as a product of energy renewal must be explicitly and under the responsibility of local actors. Likewise, the participation of the scientific community in the processes of project impact evaluation and its systematization as a case for future interventions should be promoted. Below, aspects to be considered at the beginning and closing of the project are detailed as lessons learned.

Process: The "soft factors" play a fundamental role in the selection of a pilot project: The implementation phase of the renovation of the Juan XXIII EI in Monteria was completed successfully, thanks to the support of the school management and the Mayor's Office. Therefore, when selecting a pilot project, it is important to ensure that local stakeholders identify 100% with the project. To continue with continuous improvement, actions must be planned after the completion of the intervention so that resources can be available for the required maintenance and empowerment of the community.

Public procedures have their own logic, characteristics, and speed of decision: They must be selected through public or private bidding in accordance with the laws for design consultancy, hiring for the construction of projects, and auditing for monitoring the consulting and construction.

Planning stages should not be omitted: The diagnosis and initial studies allow a rapid evaluation of the optimal measures and the identification of existing risks/problems (state of the structures, the electrical system, projected calculations of energy demand). These must be executed by entities completely independent of those that will execute the project and must explicitly establish agreements with local entities that guarantee the care and maintenance of the investment.

The designs and detailed engineering must be included in the bidding documents and must have been prepared by a company independent of the one that will carry out the job. It is important that the bidding documents include detailed engineering and that the company is carefully selected. This ensures the following of clear guidelines and allows control over the project budget. In addition, it will allow the demand for a certain level of quality from the construction company.

Guarantee the presence of independent technical experts to ensure quality control, especially during construction: The supervision of the work on site must be ensured by a technical expert on a regular basis to identify possible failures on time and be able to correct them. The expert must be independent from the construction company. In this way, the auditing choices can be guaranteed in accordance with the requirements of the specifications in terms of quality and national and international regulations.

Ensure the presence of local experts and entrepreneurs who participate in the planning and execution of the project. They must participate in the project team and must be trained so the local knowledge and characteristics can be integrated into the planning and execution of the project. Local companies can be trained for this work (including maintenance).

Use of a first block as a pilot: In the case of Juan XXIII EI, it was very useful to carry out a block as a first stage and evaluate and discuss the result intensively. This gives the companies and specialists carrying out the project very specific advice to avoid errors and optimize the rest of the work.

Organize monitoring from the beginning: To demonstrate the effectiveness of the energy renovation, it is very useful to have photos and/or videos from the same points of view; and, thus, compare the before and after. It is also necessary to have suitable monitoring that supports the impact that the quality of the indoor environment has on academic performance. Monitoring criteria should have been selected at an early stage to have baseline measurements. Likewise, these must continue with some regularity after the completion of the intervention, this is where local actors at a technical, scientific, and financial level play an important role and are the fundamental piece for the continuous improvement of the intervention.

Include an operation and maintenance plan: An operation and maintenance plan must be prepared to ensure that the quality of the interventions is maintained over time. This must be included in the project schedule and delivered by the construction company. Evaluate the cost-benefit of air conditioning systems that become a bottleneck due to the maintenance and care they require if there is no continuous monitoring process after the intervention is operationally delivered.

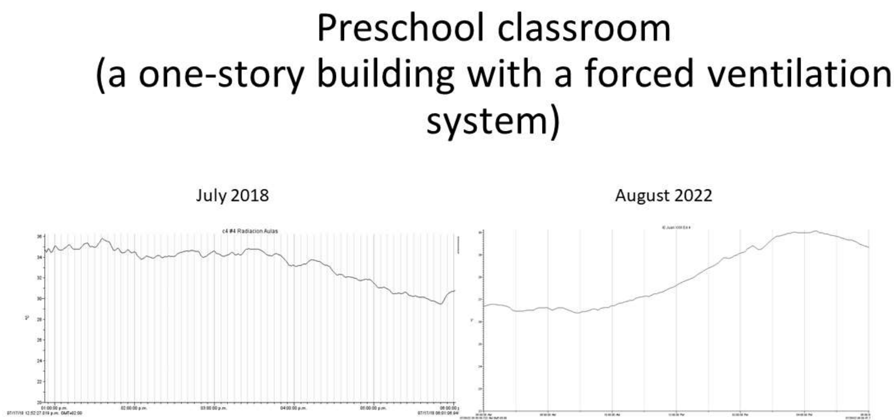
Communication participation: Public EIs are excellent platforms for the implementation of pilot projects: Public EI energy renovations not only raise awareness among students and teachers but also among parents. The Monteria pilot project aroused great political interest in the Municipality.

Political actors, both at the level of the Municipality and the state government, should participate in the pilot projects. For the projects to be carried out successfully, those responsible at the community level (mayor) as well as at the national level (Ministry of Energy and Mines, etc.) must be informed and included in the pilot projects. This must also involve subsequent commitments for continuous improvement and implementation in other settings, taking into account the relevance of the project to the environment, health, and progress of the country.

Organize the participation of beneficiaries in a participatory process from the beginning of the project: Key actors for the project must be consulted and informed from the beginning of the project. It is beneficial to consult students and teachers about the planned measures to involve them in the process. They may have new ideas or see aspects related to the use that were not taken into account. It also helps if they are patient during the execution and take care of the building afterward because it is also "their" project. This also implies participation and agreement with the beneficiaries in subsequent stages to guarantee the transfer of knowledge and the adoption of good habits to care for the investment made.

Expectations must be managed: The information communicated must be controlled, and there must be a clear direction for this. Indeed, it is difficult to react to unmet expectations afterward. A case that was presented in the EI was the belief that there would be no power outages because there was energy available.

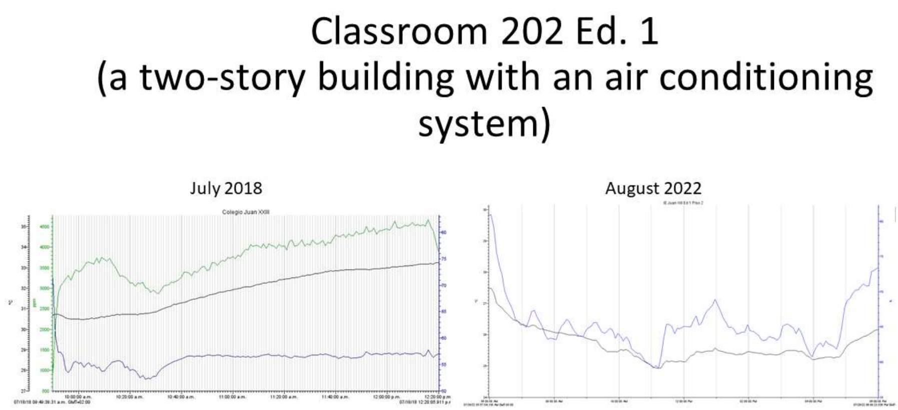
Communicate regularly about the progress of the project: From the planning stage, it is possible to communicate about the project using local media. This increases its political



July 17 between 1:00 p.m. and 6:00 p.m.	Temp, °C
Minimum	29
Average	33
Maximum	36

	Temp °C		HR %	
	6am a 6pm	1pm a 6pm	6am a 6pm	1pm a 6pm
Minimum	26.1	26.1	61.9	61.9
Average	28.8	28.9	75.4	74.8
Maximum	32.3	32.0	83.6	83.6

Fig. 2: Measurements before and after energy renovation in a Preschool Classroom (a one-story building with a forced ventilation system).



9:50am a 12:20pm	Temp, °C	HR, %	CO2, ppm
Minimum	30	52	2063
Average	32	56	3809
Maximum	33	60	4675

	Temp °C		HR %	
	6am a 6pm	9am a 1pm	6am a 6pm	9am a 1pm
Minimum	24.8	24.8	58.4	58.4
Average	26.3	26.3	70.0	72.4
Maximum	28.2	28.2	90.2	90.2

Fig. 3: Classroom 202 Ed. 1 (a two-story building with an air conditioning system).

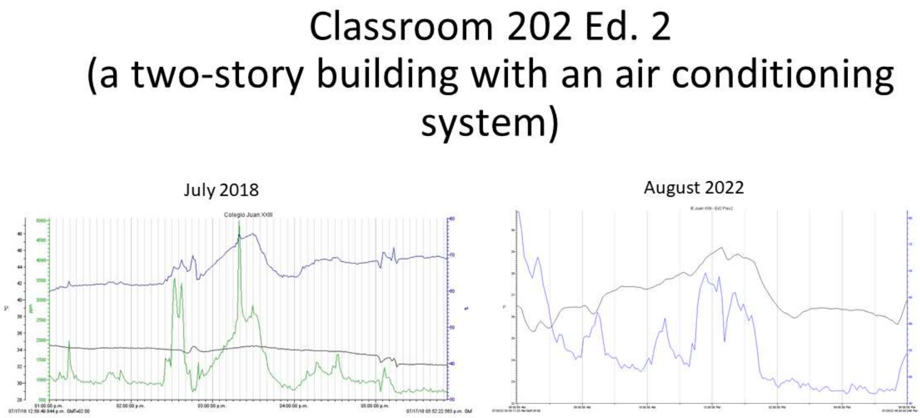
weight and can motivate other actors to participate in the project. Furthermore, your project can inspire others at the local level and, thus, participate in a virtuous chain for improving students' comfort with reduced impact on the environment. Taking photos and/or videos from the same points of view during each stage allows you to compare the before and after, justify the work, and demonstrate the results, in addition to motivating others. A public presentation of the results at the end of the construction project is very beneficial. Subsequent meetings must also be established to evaluate the impact and to propose improvement actions according to the evolution of the products and results obtained.

Variations in relation to temperature, relative humidity, and CO_2 before and after renovation: From the baseline taken before carrying out the energy renewal process at the Juan XXIII EI, it was possible to establish differences between the variables Temperature, Relative Humidity (RH), and CO_2 in the three types of interventions carried out. Below are the results of the comparison between the measurements carried out.

Fig. 2 shows the measurements carried out during 2018 and 2022 in a Preschool Classroom (a one-story building with a forced ventilation system). A decrease in average temperatures is marked.

Fig. 3 shows the measurements carried out during 2018 and 2022 in classroom 202 Ed. 1. A decrease in average temperatures is also observed. In this case, a greater difference is marked since air conditioners were used.

Fig. 4 shows the measurements carried out during 2018 and 2022 in classroom 202, Ed. 2 (a two-story building with



1:00am a 6:00pm	Temp, °C	HR, %	CO2, ppm
Minimum	32	60	646
Average	34	66	1215
Maximum	35	76	5000

	Temp °C		HR %	
	6am a 6pm	1pm a 6pm	6am a 6pm	1pm a 6pm
Minimum	22.7	22.7	46.8	46.8
Average	26.9	26.1	59.6	60.5
Maximum	31.4	29.5	85.0	85.0

Fig. 4: Classroom 202 Ed. 2 (a two-story building with an air conditioning system).

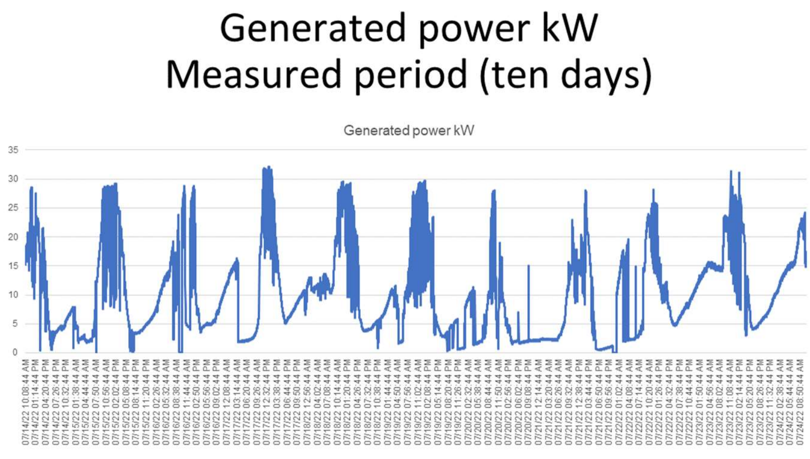


Fig. 5: Generated power in kW for 10 days.

an air conditioning system). The consistency is observed between the measurements in Figs. 3 and 4. For both rooms, air conditioners were used.

Fig. 5 shows the measurements made of the power generated in 10 days, presenting the generation of photovoltaic energy due to the energy renovation carried out.

Perception of the educational community of the resulting comfort conditions after the intervention: One of the most evident results was the increase in the demand for new student openings in Juan XXIII EI in 2022 after the intervention was completed. The increase was around 29% compared to 2019. This could be interpreted as the community's perception of an EI with better capacity, comfort, and/or quality based on changes in infrastructure (Fig. 6).

According to Figs. 7, 8, and 9, the community of the educational institution that participated in the survey stated that thermal comfort had improved and that they felt satisfied with the current temperatures.

According to Figs. 10, 11, and 12, the community of the educational institution that participated in the survey stated that lighting comfort had improved and that they felt satisfied with the current conditions.

According to Figs. 13, 14, and 15, the community of the educational institution that participated in the survey stated that acoustic comfort had improved and that they felt satisfied with the current conditions.

CONCLUSIONS

The experience with the development of this project allowed

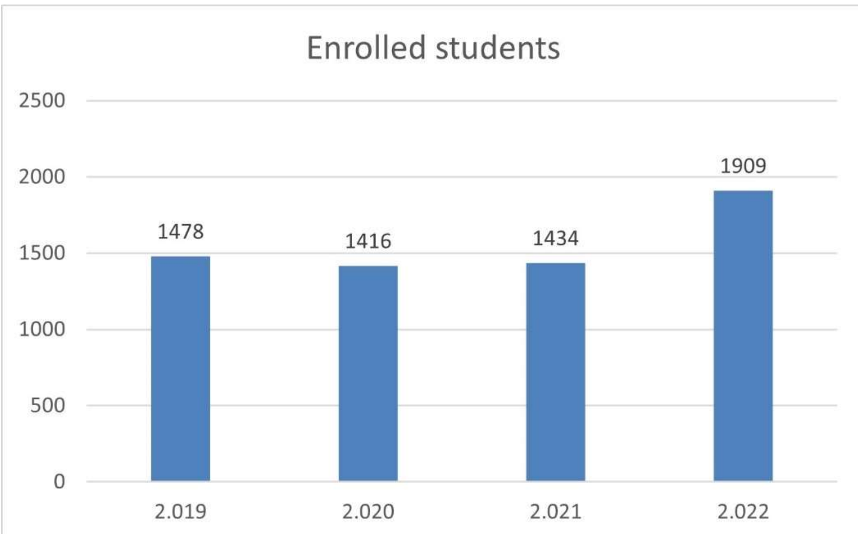


Fig. 6: Number of students enrolled per year.

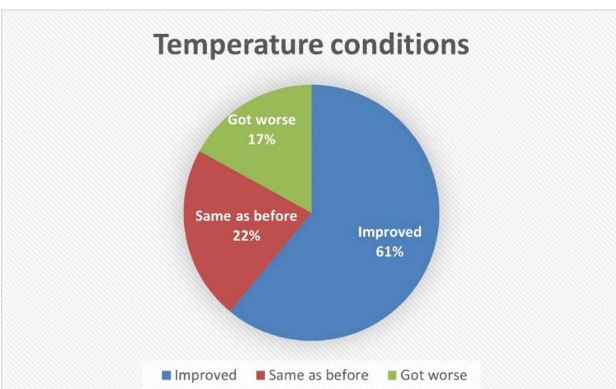


Fig. 7: Temperature conditions.

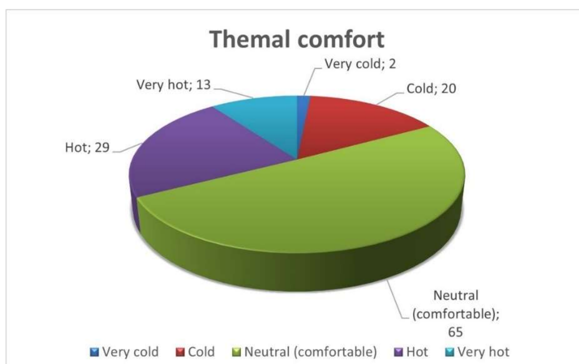


Fig. 8: Thermal comfort.

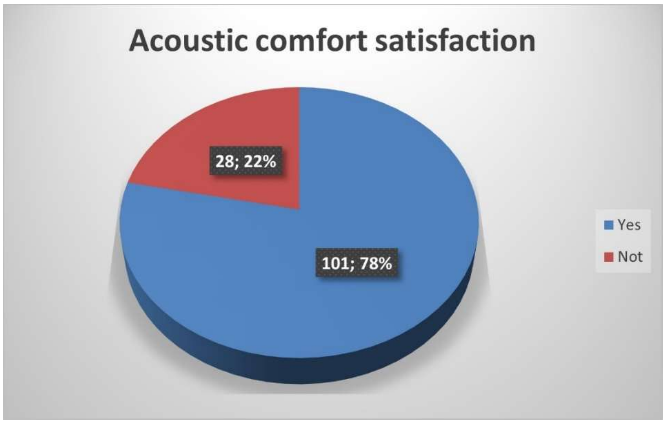


Fig. 9: Results for the questions related to thermal comfort.

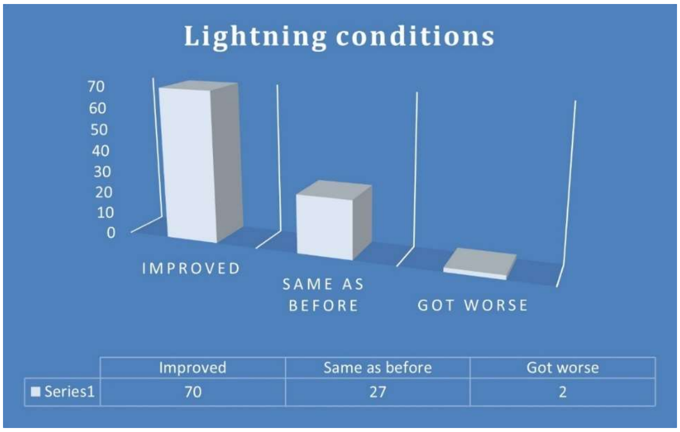


Fig. 10: Lightning conditions.

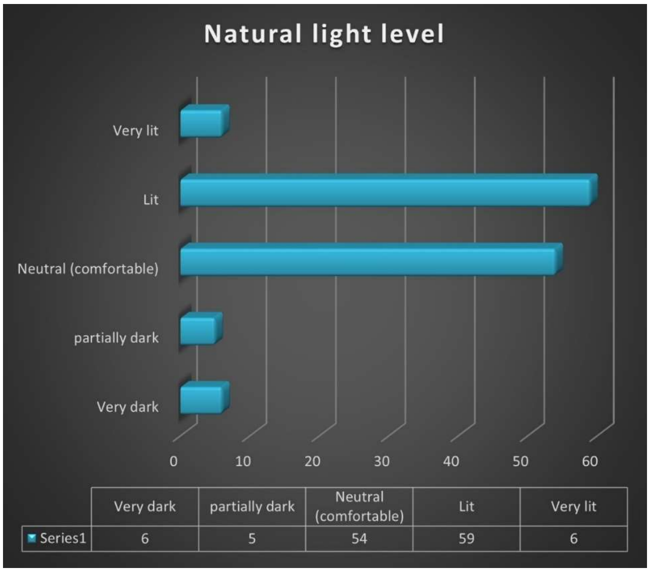


Fig. 11: Natural light level.

Fig. 12: Results for the questions related to lighting comfort.

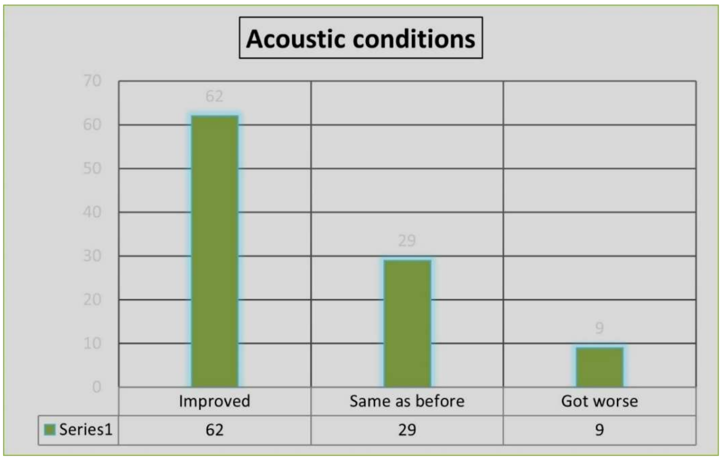


Fig. 13: Acoustic conditions.

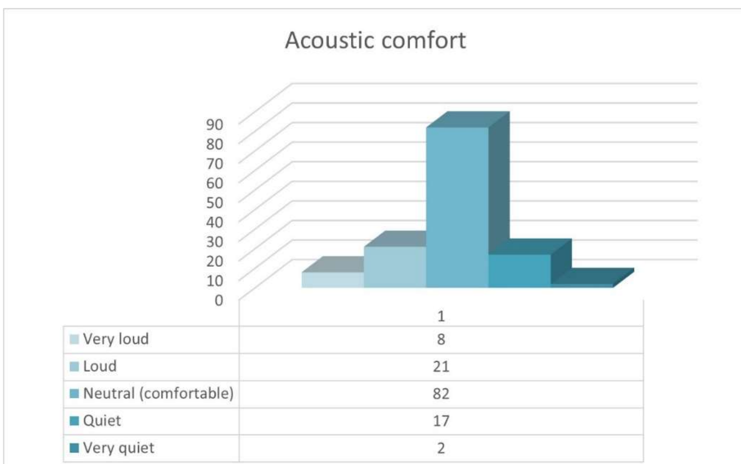


Fig. 14: Acoustic comfort.

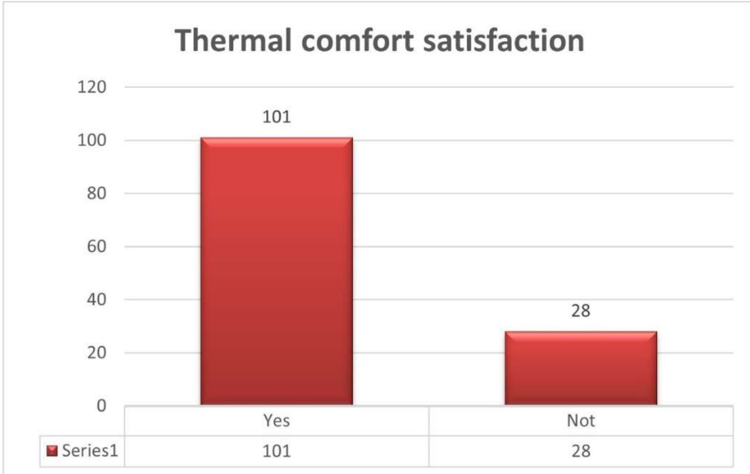


Fig. 15: Results for the questions related to acoustic comfort.

us to identify important success factors and desirable conditions for the development of these types of projects, which are detailed in Chapter 8 of the technical report (Booklet for energy renovation of schools in hot, humid climates of Colombia 2021).

These factors generally support these four major aspects to highlight:

- Energy renovation in schools in warm climates is essential to improve the thermal comfort conditions of the educational community. It can be achieved with simple but substantial measures, such as pergolas, new windows, and efficient air conditioning and ventilation systems. Furthermore, this improves the reputation of the school, causing collateral benefits such as what happened at the Educational Institution where there was an increase of openings by approximately 29% in the number of students. Additionally, Educational Institutions where energy renovations are implemented demonstrate a willingness to innovate and are in sync with the environmental and educational concerns of the moment. This is a component that contributes to the institutional image as an educational establishment.
- Energy renewal in Educational Institutions offers significant savings in operating costs and greenhouse gas emissions. This reduction in emissions is estimated at 59 tCO_2 per year in the case of the Juan XXIII EI. The cost of avoiding the emission of one tCO_2 is estimated at 28 USD. A positive outcome is the support of Colombia's compliance with international climate change mitigation goals and the reduction of energy service costs.
- Energy renovation in Educational Institutions indirectly leads to the renovation of important structural and architectural elements; therefore, the investment costs are reflected in the longer useful times of the building and an improvement in its quality in the long term.
- The experience of renovating a building such as an Educational Institution is an excellent way to raise awareness among new generations about the benefits of energy efficiency and the use of renewable energy. The EI has a room where students are taught in a didactic way the benefits that were achieved in their school and how they contribute to sustainability.

Financing

Guarantee financing for the entire project: In the case of Juan XXIII EI, financing for all stages of the project was assured through the Energy Efficient City Initiative. It is important to ensure not only the financing of the execution but also the planning, consulting, review, and quality control of the project. Additionally, a later margin of time to make up for shortcomings in local action must be considered, and commitment by national and international actors must be generated before the final closure of the intervention.

Implementation Budget: As a planning element, it is important to consider an analysis of technical specifications, quantities, and prices prior to construction and/or intervention that ensures compliance with the objectives defined in the planning and design stage.

Have a reserve: It is necessary to reserve a larger budget than estimated from the beginning to be able to face unforeseen events. 10% of the gross value is recommended as a reserve. This value could also be used for the post-intervention phase.

Consider operating costs: Measures that can reduce or keep the operating costs of the EI low must be considered in the project. This will facilitate the administration of the school. Local governments must commit the necessary financing for the correct operation and proper maintenance of the systems.

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