Energy Efficiency in Public Buildings: A Step toward the UN 2030 Agenda for Sustainable Development

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Abstract: Within the context of the UN Sustainable Development Goals for the Agenda 2030, this article aims to explain and understand the usefulness of energy audits and their potential to reveal energy efficiency opportunities in a small public building located in northwestern Mexico. The methodological structure was adopted from the Cleaner Production–Energy Efficiency Manual published by the United Nations Program for the Environment. A case study approach was employed to examine how energy audits might potentially increase energy efficiency opportunities in the participating building. Amongst the findings, the primary source of energy wastage was occupants’ behaviors. Furthermore, this study showed that energy audits could be useful to establish a baseline in situations where previous data were not available, to allow comparisons as well as to identify opportunities in old buildings for the purpose of increasing their energy efficiency performance. As a practical implication of this research, the Sonora government can be in a better position to assist the Mexico federal government in reaching some of the country’s General Law on Climate Change objectives, particularly the one related on cutting down greenhouse gas emissions by 30% by the year 2020, and 50% by the year 2050, compared to those registered in 2000.

Keywords: energy audits; energy efficiency; public old buildings

1. Introduction

Since January 2016, various organizations around the world have committed to achieve the sustainable development goals (SDGs) specified in the United Nations Agenda 2030, such as General Mills, Kimberly-Clark, Siemens, and others [1]. The SDGs intend to alleviate poverty, inequality and climatic and environmental degradation, and to promote prosperity, peace and justice [2]. Even though each of the seventeen SDGs is important, the United Nations (UN) has stated that “the goal to achieve affordable and clean energy is especially important as it interlinks with other SDGs” [3].

With an increase in the prices of electricity and gas, customers are relentlessly pursuing various strategies to achieve cost reduction. For example, in the United States of America, the average price of a kWh of electricity to ultimate customers in July 2019 was 0.3% higher than that in July 2018 [4]. This increasing trend is likely to continue in the foreseeable future because of increasing costs in the energy market with respect to various resources, including crude oil and natural gas [5]. Various organizations have traditionally implemented energy management systems (EnMSs) to reduce the consumption of electricity and other energy sources, and to minimize the emission of greenhouse gases (GHGs). The primary outcome of an EnMS is a detailed report that outlines the energy efficiency performance of an organization that can be used as a methodology for increasing energy efficiency awareness, and ensuring continuous organizational improvement [6].
The International Organization for Standardization (ISO) 50,001 standard is one of the most popular frameworks among the various guidelines that are available for establishing EnMSs. According to Marimon and Casadesús [7], this standard was designed in accordance with the structure of other standards belonging to the ISO family. Further, ISO 50,001 is a type of spinoff specification standard obtained from ISO 14,001. It exhibits requirements similar to those of ISO 14,001 with respect to energy efficiency, and also helps organizations to achieve the ISO 50,001 certification [8]. Furthermore, ISO 50,001 can be used as a guide to develop, monitor and improve energy-efficient initiatives (Lopes de Sousa et al., 2017). The ISO 50,001 standard has been used as a national and regional standard in several countries, including Germany, France, Spain, India and China [9]. According to the ISO, ISO 50,001 helps organizations to enhance their corporate image to and reduce the environmental impacts associated with their production operations, while reducing the costs and improving the competitiveness [10].

A core component of any EnMS is to audit the energy flow throughout a process or system, in order to determine its energy inefficiency with respect to the productivity and profitability. An energy audit is a tool that helps companies to routinely evaluate, maintain and identify opportunities for improving their energy efficiency [11,12]. Further, it is also a mandatory requirement for obtaining an EnMS certification [13].

Energy audits are not only used in industrial settings, but are also relevant to understand the energy efficiencies of various buildings, including residential, commercial and public buildings. These energy audit reports allow the owners, tenants and managers of buildings to understand the energy use in the building, identify the sources of energy waste, and explore opportunities to implement the energy conservation measures [14,15]. The energy audits usually reveal several opportunities for improving energy performance despite the unique characteristics of each building. Achieving energy efficiency in buildings introduces several benefits. For instance, reduced energy use for space heating and cooling; reduced electricity use for lighting, office machinery and domestic type appliances; lower maintenance requirements; improved comfort; enhanced property value [16], as well as reductions in greenhouse gas (GHG) emissions and operating costs [17].

Energy audits can also be useful to benchmark good energy-efficient practices. Energy benchmarking is known as “the practice of accounting for and comparing a metered building’s current energy performance with its energy baseline or historical performance or comparing a metered building’s energy performance with the energy performance of similar types of buildings” [18]. Several acceptable energy-benchmarking methods have been mentioned in the literature for determining the energy performance; each method has its own set of limitations, and the current energy-benchmarking methods are no exception. One such limitation is that energy benchmarking focuses on technical solutions, such as upgrading the air conditioning, heating, or lighting systems, rather than on achieving large-scale behavioral changes [19,20]. This can prevent the success and implementation of these methods.

The current trends denote that energy consumption will increase in the institutional and commercial buildings in the future [21]. Because the building sector is essential for the socioeconomic development of a country, improving its energy efficiency is important, albeit challenging [22]. Often, energy audits lead to the retrofitting of buildings according to the Advanced Energy Retrofit Guide [23]. Retrofitting can result in significant energy savings by implementing the commissioning of the existing buildings, standard retrofits and deep-retrofit initiatives that involve little investment. However, several variables limit the energy performance. Some of the considerably significant impacts include building envelopes, building systems, operation and maintenance, occupant behavior and indoor environmental conditions [24]. The building size also poses a challenge to achieve an acceptable energy performance, because the owners of small- and medium-sized buildings usually do not have the expertise or knowledge required to identify opportunities or evaluate cost-effective retrofitting technologies [25]. Finally, the obsolescence of a facility and its electrical appliances may reduce the opportunities to improve the energy efficiency of a building [26,27].
Based on this summary, there is significant potential to increase the energy efficiency and energy performance of a building, regardless of the significant challenges [28,29]. Indeed, energy audits play a crucial role in ensuring energy efficiency, because they are an excellent tool for the initial diagnosis of the energy assessment of a building. They also enable opportunities to improve the energy efficiency of a building by monitoring the efficacy of the energy conservation projects implemented to achieve a suitable energy performance.

The objective of this study is to explain and understand the usefulness of energy audits and the potential of energy efficiency opportunities through an idiographic case-study analysis of a small public building. The strength of this case study and an important contextual feature is that it includes a review of the institutional struggle of a Mexican Governmental Agency to satisfy the demands of Mexico’s General Climate Change Law under adverse conditions. Such contextual features are often absent in the published literature related to energy audits.

2. Methodology

The methodological structure for this study was adopted from the Cleaner Production and Energy Efficiency (CP–EE) Manual published by the United Nations Environment Program (UNEP) [30]. This manual provides elements that are necessary for conducting in-house assessments, either by the facility personnel, or by the cleaner production professionals who are not necessarily energy efficiency specialists. The CP–EE assessment methodology includes the following main stages: planning and organization, pre-assessment, assessment, feasibility analysis and implementation and continuation. This scheme comprises 18 tasks grouped into five phases, which are presented in Figure 1. Because this study mainly concentrates upon energy audits, the focus of this case study is to obtain an outcome to task number 14. The entire study was conducted from January to October 2018 in a small public building located in northwestern Mexico. The walk-through assessment was conducted for twelve weeks, from July 16 to October 5. It is essential to highlight that this study period was selected, since it is when there is more potential energy demand for this region.

![Figure 1. The United Nations Environment Program (UNEP) Cleaner Production and Energy Efficiency framework. Source: UNEP [30].](image-url)
The audit approach contained three avenues. The first avenue intended to characterize the building to identify the heat-transfer sources or routes, either for heat-loss or heat-gain situations. The heat-transfer sources included the spaces/cracks in walls, roofs, windows and doors from where heat leakage occurred. When the air conditioning units were turned on, the heat-transfer sources were recorded, and classified as severe, moderate, or low, depending on the size of the hole or space from where the heat was escaping.

Because this is a non-metered building, the second auditing avenue focused on estimating the energy demands of the air conditioners, office appliances and lighting. Therefore, there was devised an inventory list to include the description of the appliance, its energy requirements, and its physical shape. In addition, the electrical installation conditions were observed. Although it was not possible to quantitatively calculate the loss of wattage due to the deteriorating conditions of the appliances, lighting and electrical installations, it was possible to record the qualitative warnings that indicated the need for maintenance.

The third auditing avenue focused on observing in-situ energy-related occupant behaviors. The auditors monitored and registered the manner in which the occupants used the energy appliances, lighting and air conditioners throughout the summer. Further, there was calculated the energy wastage, by considering the energy demand of the appliance involved in the wastage of energy, and multiplying it with the period of use.

Finally, there was conducted a thermographic study along with the audit as a complementary strategy to identify the equipment failure risks, check the load centers in electrical installations and detect thermal bridges. Subsequently, it was used a thermal imaging camera and conducted an electronic diagnosis using a hook ammeter for conducting this analysis. The thermal imaging camera allowed us to detect the hotspots in critical areas of the equipment such as condenser and fan motor. It was used a hook ammeter to verify the current through the appliances and equipment.

3. Results

3.1. Background

The General Law on Climate Change (LGCC by its acronym in Spanish), developed in October 2012 and amended in July 2018, is the primary policy instrument in Mexico for counteracting the climate change. It establishes an objective of reducing GHG emissions by 30% by 2020 and by 50% by 2050 when compared with the emissions registered in 2000 [31]. In addition, Mexico has unconditionally committed to decrease emissions by 22% by 2020 [32]. To achieve these objectives, LGCC requests that the federal entities should elaborate and implement appropriate climate change programs. Therefore, the State of Sonora entered into a strategic alliance with the Sustainable Graduate Program at the University of Sonora through the Ecology and Sustainable Development Commission of Sonora (CEDES by its acronym in Spanish) to develop a joint program for increasing the energy efficiency of the public buildings of the Sonoran Government. The CEDES program was aligned with the objectives of the LGCC and with the National Climate Change Strategy: Vision 10-20-40 (ENCC by its acronym in Spanish), a valuable planning instrument that defines Mexico’s long-term vision, and guides Mexican decision-makers with respect to climate change. The ENCC establishes several lines of action that can serve as strategic pillars, among which two, in particular, were incorporated into the CEDES energy efficiency program. The first pillar is aimed at reducing the energy intensity by promoting responsible consumption, whereas the second pillar aims to promote decarbonization in buildings [33].

Electricity is the standard type of energy source found in a public building; therefore, the strategic objective of this audit is to increase the electrical energy efficiency, i.e., to reduce the energy demands from an electrical system without disrupting the daily activities in the building. To accomplish this strategic objective, the audit program encompassed three important avenues, as mentioned earlier in the methodology section.
3.2. Infrastructure Audit

3.2.1. Building Profile

To evaluate the energy wastage, the building was characterized to determine the used construction materials and their thermal transmittance and thermal resistance, as well as other characteristics related with the thermal behavior of a building. The administration did not possess this information before performing this characterization. The energy-audited two-story building is part of a 19-building complex belonging to the Ecological Center of Sonora. It was built in 1985 in the natural habitat of the Sonora Desert. This building concentrates most of the electricity users and electrical office appliances within the following six areas: administration, cafeteria, cafeteria store, audiovisual room, terrace and toilets.

Several factors determine the electricity demand in the building necessary to maintain a comfortable internal temperature; one is the heat extraction necessary to reduce the high temperatures. The average temperature in situ when the audit was conducted was 40 °C, although even more extreme temperatures (over 45 °C) are common in northern Mexico during summer. The thermal transmittance (U-value) and thermal resistance (R-value) of the building materials, the dimensions of the materials, and even the orientation of the materials relative to the cardinal points of the compass were used to determine the heat flow. The building is shaped similar to an irregular polygon encompassing a total area of 1542 m2, with a sloping roof made of plywood. The exterior walls were mostly built of concrete blocks, although a few areas were constructed using bricks or other materials, such as glass and wood. The interior walls were built with bricks, with a wooden pine cover. In the upper floor, the northwestern side was built using wood, and there were glass windows.

On the northeast side of the building, the area of the concrete block wall was 123.7 m2, and it contained five glass windows with a total area of 5.25 m2. On the northwestern side of the building, the wall covered an area of 120.95 m2, with 12.1 m2 of glass windows. On the north side of the building, there was just a glass window with an area of 32 m2. On the west, the wall covered an area of 189 m2, with 28 m2 of glass windows. On the south, there were 46.97 m2 of concrete walls and 19 m2 of glass windows. On the southwest, there was only a wall with an area of 48.50 m2. The concrete blocks exhibited a thermal transmittance of 1.05 W/m2 °C and a thermal resistance of 0.3488 m2 °C/W. The glass has a thermal transmittance of 5.26 W/m2 °C and a thermal resistance of 0.2262 m2 °C/W, whereas plywood has a thermal transmittance of 0.56 W/m2 °C and a thermal resistance of 1.79 m2 °C/W.

Vegetation also plays an essential role in determining the microclimate of the building. Desert plants surround all of the building. On the north side of the building, there are cacti, mesquites, palms and Ficus benjamina that all provide shade to the administration office on the second floor. To the northwest and the southwest, just grass and hedges can be observed, which leaves that side of the building without any protection from the sun for the majority of the day. Cacti, mesquites, paloverde trees, Parkinsonia aculeata and magueys surround the southern part of the building. Because they have much foliage, this part of the building is provided with shade during the day. However, plants with low foliage density surround the western part of the building, allowing the sun to heat that side during the day. Shading accounts for about 20% of the total area of the building.

3.2.2. Heat Transfer through Walls, Roof, and Windows

The conduction of heat from the exterior to the interior is one of the main mechanisms leading to the accumulation of heat in the interior of this audited building, especially during the summer. Understanding the energy performance of the building envelope was crucial for determining the amount of energy that was required for cooling. Therefore, once the building was characterized, the heat transfer through the main materials along the outer perimeter was calculated using the following equation (see Table 1 for the explanation of the factors):

\[
\text{Heat Transferred} = \frac{\text{Surface Area (Exterior temperature – Interior temperature)}}{\text{R-Value}} \tag{1}
\]
Source: Rimstar [34].

Table 1. Explanation of the factors.

| Factor                  | Value               |
|-------------------------|---------------------|
| **Surface Area/R-values** |                     |
| Block: R-Value          | 0.3488 m² °C/W     |
| Glass: R-Value          | 0.2262 m² °C/W     |
| Plywood: R-Value        | 1.79 m² °C/W       |
| **Average Temperatures** |                     |
| Interior                | 25 °C               |
| Exterior                | 41 °C (in summer)   |

Note: The R values for block and glass were calculated according to the materials the thermal conductivity values, and the calculation procedure for thermal resistance is indicated in the NOM-008-ENER-2001 of energy efficiency in buildings, the envelope of non-residential buildings. The R-value of plywood is taken from ASHRAE [35].

As presented in Table 2, the North-East side, North-West side and the zenith of the building allow high heat transfer rates.

Table 2. Heat transferred from outdoors to indoors.

| Cardinal Direction              | Heat Transferred (kW/m²) |
|---------------------------------|--------------------------|
| Northeast Side                  | 0.54                     |
| Northwest Side                  | 0.45                     |
| Zenith                          | 0.28                     |
| South Side                      | 0.19                     |
| Southeast Side                  | 0.15                     |
| West Side                       | 0.12                     |
| Southwest Side                  | 0.09                     |
| North Side                      | 0.07                     |
| Sloped Roof To Northwest Side   | 0.02                     |
| Sloped Roof To South Side       | 0.01                     |
| Sloped Roof To West Side        | 0.01                     |
| Sloped Roof To Southwest Side   | 0.01                     |
| **Total**                       | **1.92**                 |

3.2.3. Heat Infiltration/Exfiltration Transfers

Another important heat transfer mechanism is derived based on the movement of air with different temperatures because of convection. The cracks/holes in the building envelope, doors, windows, walls, ceilings and roofs are sources of air leakage that can cause heat infiltration or heat exfiltration, which may reduce the thermal comfort associated with the building. When the latter occurs during the summer or even earlier or later in the year, the occupants of this building usually turn on the air conditioner to regulate the indoor temperature and to maintain thermal comfort at a level at which an optimal amount of work can be achieved. This increases the energy consumption and leads to energy wastage. To understand the magnitude of this wastage, it is necessary to know the manner in which air conditioners function. The “mini-split” technology works using an indoor unit and an outdoor unit. The indoor unit blows warm air from an area over cold evaporator coils, through which a refrigerant is run to absorb the heat from the air. The refrigerant subsequently transfers the heat to the outdoor unit, which discards it into the atmosphere.

Contrary to popular belief, most of the heat in an area originates from the mass in the area and not the air itself, because it has a lower specific heat when compared with those of the materials in
the walls, roof, windows and devices. Therefore, the contribution of heat infiltration to the total heat in the building should not be a major concern.

Even though it is theoretically accurate that entryways and exits which allow unintentional and uncontrolled air flows can destabilize the thermal comfort of an area, appropriate ventilation is also necessary to expel the buildup of pollutants and bacteria from the building.

While various studies and experimental tests have concluded that air infiltration impacts the energy consumption in a building, there is no agreed-upon consensus about the magnitude of this impact. Some studies estimated that infiltration accounts for 20%–50% of a building’s energy demand [36,37]. Calculating the energy wastage attributable to air infiltration is not an easy task, because it involves external factors, such as the exterior temperature, air humidity and total mass of the building. Therefore, our auditing team considered it appropriate to determine a “factor” to estimate the amount of energy wastage due to infiltration/exfiltration sources, instead of using extremely complicated mathematical equations associated with a high degree of uncertainty that would require the use of computational-fluid-dynamics modeling software. The factors used were directly proportional to the sizes of the heat-transfer routes. For holes bigger than 100 cm², there was used 30% of the energy demand of the air conditioner in that area; for moderate holes having sizes between 25 and 100 cm², there was used 15% of the energy demand of the air conditioner in that area; and for holes smaller than 25 cm², there was used 5% of the energy demand of the air conditioner in that area.

The auditing team identified six routes from which heat was transferring, causing loss of cool air, and making the air conditioners work longer than previously assumed. Two among the six transfer routes were classified as severe, and the remaining four as light. Also, there were found cracks and small gaps in some of the building materials. In total, it was estimated the energy wastage to be 1188 kW from July 16 to October 5, 2018 (see Table 3). Instead of accurately quantifying heat infiltration, identifying the heat-transfer routes is essential to suggest improvements in a building. The energy wastage associated with heat infiltration was calculated based on the following Equation:

\[
\text{Kilowatt (kW) wastage per infiltration/exfiltration} = \text{energy consumption in kW by air conditioners in the area} \times \text{consumption period} \times \text{factor}
\] (2)
Table 3. Energy wastage due to heat infiltration/exfiltration.

| Area                | Kilowatt AC (from Table 4) | Severe Frequency | Moderate Frequency | Light Frequency | Energy Wastage in kW | Hours of Consumption | Total Energy Waste, kW, in the Audited Period |
|---------------------|----------------------------|------------------|-------------------|----------------|----------------------|----------------------|-----------------------------------------------|
| Administration Rec  | 2.28                       | 2                | 1.368             | 0              | 0                    | 1.368                | 480                                          | 656.6                                         |
| Administration S    | 1.16                       | 0                | 0                 | 0              | 0.058                | 0.058                | 480                                          | 27.8                                          |
| Audiovisual Room    | 50                         | 0                | 0                 | 0              | 3                    | 7.5                  | 67                                           | 502.5                                         |
| **Total**           | **2**                      | **0.37**         | **0**             | **4**          | **7.56**             | **8.926**            | **1027.2**                                   | **1186.9**                                    |
3.3. Equipment and Appliance Audit

Because this is a building without a monitoring system, the second auditing avenue focused on the estimation of the energy demand of the air conditioners, office appliances and lighting. The Ecological Center administration is renovated every six years. Over the years, the technical manuals of the equipment have been lost; therefore, there was created an inventory list to register the descriptions of the appliances, their energy requirements, and their physical shapes. Understanding the energy requirements of each piece of equipment and appliance was a major challenge, because many technical labels were absent from the chassis or were not legible. As an alternative method, there was taken a picture of the appliance and researchers searched on the Internet for obtaining a manual of a similar appliance. If this failed, the auditors queried professional technicians or dealers whether they knew the characteristics of the appliance. During the inventory, it was observed and recorded as to the conditions of the electrical installations. The total estimated energy demand in the audited building was 82.41 kW. Table 4 presents the energy demand breakdown by area.

| Location            | Electrical Equipment, Lighting and Appliances (kW) | Total kW |
|---------------------|---------------------------------------------------|----------|
|                     | Illuminating | AC | Computer Equipment | Others |          |
| Adm. Reception      | 0.51         | 2.28 | 3.03               | 0.55   | 6.37     |
| Adm. Education      | 0.32         | 1.16 | 1.64               | 1.2    | 4.32     |
| Adm. Sub-direction  | 0.32         | 1.16 | 0.25               | 0      | 1.73     |
| Adm. Secretarial    | 0.32         | 1.16 | 0.65               | 1.2    | 3.33     |
| Adm. Direction      | 0.51         | 1.16 | 0.65               | 0.115  | 2.44     |
| **Total Administration** | **1.98** | **6.92** | **6.64** | **2.95** | **18.49** |
| Cafeteria           | 0.52         | 0   | 0.49               | 4.25   | 5.26     |
| Audiovisual room    | 2.188        | 50  | 0.287              | 3.62   | 56.10    |
| Toilets             | 0.256        | 0   | 0                  | 0      | 0.26     |
| Terrace and circulation | 0.096    | 0   | 0                  | 2.2    | 2.30     |
| **Total**           | **2.284**    | **6.95** | **6.62** | **2.95** | **82.41** |

Although it was not possible to quantitatively estimate the energy wastage because of the deterioration of the appliances, lighting and electrical installations, it was possible to issue qualitative warnings to indicate the need for maintenance of the air conditioners or appliances.

3.4. Energy Behavior Audit

The third auditing avenue focused on observing in-situ, energy-related occupant behaviors. The auditors monitored and registered the manner in which the occupants used the office appliances, lighting and air conditioners throughout the summer. In particular, it was expected the doors and windows to be closed when the air conditioners were kept on. It was also expected to find the lighting and air conditioners off when the rooms were empty for more than half an hour. Furthermore, it was expected to find monitors and other appliances to be in the energy-saving mode when they were not in use. If this was not the case, these were recorded as energy wastage. The energy wastage in this part of the audit was classified as severe, moderate, or light. A severe wastage involved the use of an air conditioner after the end of a working day. Further, it was calculated as to the resulting wastage of energy by considering the energy demand of the air conditioner involved, multiplied with a period of 12 h. Moderate wastage involved the usage of air conditioners during the working day, and light wastage involved the usage of any other electrical appliances or lighting during the working day. The period applied to be classified as moderate and light wastage was one hour. In total, there were 113 wastage reports during the audit period, and all of these were classified as moderate wastage. Not surprisingly, the administration area accumulated most of the wastage reports. Leaving the doors open when the air conditioners were turned on was the uppermost failure in the audit report.
In total, the wastage measured in this branch of audit was 227.10 kW. Table 5 reports the energy wastage based on the occupant behavior.

Table 5. Energy wastage based on the occupant behavior.

| Area             | Kilowatts | Energy Behavior Wastage Reports | Total Wastage kW |
|------------------|-----------|---------------------------------|------------------|
|                  |           | Severe F(x) EFW: 2 h Moderate F(x) EFW: 1 h Light F(x) EFW: 1 h |                   |
| Administration   | 2.280     | 0 0 2 4.6 0 0               | 4.6              |
| Rec              | 6.920     | 0 0 20 138.4 0 0            | 138.4            |
| Administration   | 1.160     | 0 0 49 56.8 0 0            | 56.8             |
| D                | 0.512     | 0 0 14 7.2 0 0            | 7.2              |
| Administration   | 1.984     | 0 0 7 13.9 0 0            | 13.9             |
| D                | 0.320     | 0 0 14 4.5 0 0            | 4.5              |
| Administration   | 0.250     | 0 0 1 0.3 0 0            | 0.3              |
| Sub              | 0.260     | 0 0 2 0.5 0 0            | 0.5              |
| Cafeteria        | 0.220     | 0 0 2 0.4 0 0            | 0.4              |
| Cafeteria        | 0.270     | 0 0 2 0.5 0 0            | 0.5              |
| Total            | 0.0       | 0.0 113.0 227.1 0.0 0.0 | 227.1            |

3.5. Thermography Report

To conduct detailed exploration for achieving energy-efficient opportunities, there were captured the infrared thermal images of the air conditioners, appliances and lighting, building envelopes, walls and windows. It was also inspection of the switch load centers and electrical installations. It was found the lighting and appliances to be working under ideal conditions. Majority of the air conditioners were consuming nominal current, but it was observed that one consumed more than nominal current, and was also working just under the critical temperature. Figure 2 depicts the thermal image of this air conditioner’s motor. Table 6 presents the difference between the nominal and rated current found in the air conditioner that was located in the administration area, section S.

Figure 2. Fan motor of a mini-split under critical temperature.
Table 6. Air conditioner in an inadequate working condition.

| Area       | Description | Power (W) | Voltage (V) | Current (A) | Capacitor Temperature °C | Fan motor Temperature °C | Registered Temperature | Comments |
|------------|-------------|-----------|-------------|-------------|--------------------------|---------------------------|-------------------------|----------|
| Administration S | Air conditioner 1 ton | 1160      | 220         | 5.3         | 93.8                     | 93.3                      | The fan motor was detected with a critical temperature of 90.3 °C | The hook ammeter recorded a higher current than the nominal current |
Figure 3 denotes the thermal images at the load center, showing a temperature difference of almost 40 °C with the equipment, appliances and lights off versus that observed when those devices were turned on. This situation may be attributed, at least in part, to the defective electrical connection in the building, or to the state of wiring, because there were also detected loose, melted and burned wires that can cause short circuits and energy inefficiency.

![Figure 3. Temperature difference at the load center, with the equipment and appliances being turned on/off.](image)

Finally, the thermography study confirmed the observations of the infrastructure audit, where heat infiltration into the building caused the temperatures to become greater than 30 °C, resulting in gradual loss of coldness. Figures 4 and 5 show the thermal pictures captured from the administration area, proving that the heat transfer is high when there are no soffits in the ceiling, or there are cracks in the wood floor on the second floor.

![Figure 4. Thermal picture of a ceiling with no soffits.](image)

![Figure 5. Thermal picture of a crack on the second floor.](image)
4. Analysis

It was estimated the total energy wastage during the audited period to be 1414 kW. Approximately 0.92 kW/m². By considering this as the base and using a conversion factor of 458 g of CO2/kWh issued by the Mexican Secretary of Environment and Natural Resources (SEMARNAT by its acronym in Spanish), it was estimated the GHG emission associated with this wastage estimate to be equivalent to 661.7 kg CO₂. Also, the cost of this wastage was 111.40 dollars, which was obtained by multiplying the total wastage with a tariff of approximately 1.5324 pesos per kW and dividing with an exchange rate of 19.45. In terms of energy efficiency, the estimated percentage of energy wastage was 8.6%, indicating an energy efficiency of 91.4%. Note that this estimate does not consider the energy wastage due to the poor condition of the equipment or inadequate electrical installations. Table 7 presents these calculations.

| Area                        | Estimated Energy Demand (kW from Table 4) | Audit Period (Hours) | Total Estimated Energy Demand kW | Estimated Energy-Wastage Behavior kW | Estimated Infrastructure Energy Wastage kW |
|-----------------------------|------------------------------------------|----------------------|----------------------------------|-------------------------------------|------------------------------------------|
| Administration             | 18.49                                    | 480                  | 8875.2                           | 225.7                               | 684.4                                    |
| Audiovisual room           | 56.10                                    | 67                   | 3758.7                           | 0.0                                 | 502.5                                    |
| Cafeteria                  | 5.26                                     | 480                  | 2524.8                           | 1.4                                 | 0                                        |
| Toilets                    | 0.26                                     | 480                  | 124.8                            | 0.0                                 | 0                                        |
| Terrace and circulation    | 2.30                                     | 480                  | 1104.0                           | 0.0                                 | 0                                        |
| Sub-Total                  | 82.4                                     | N/A                  | 16,387.5                         | 227.1                               | 1186.9                                   |
| Total                      | 82.4                                     | N/A                  | 16,387.5                         | 1414.0                              | 1414.0                                   |
| % energy wastage           |                                          |                      |                                  |                                     | 8.6%                                     |

As mentioned before, this study had the following two objectives: first, this study intends to explain and understand the usefulness of energy audits to reveal opportunities for increasing the energy efficiency of an old and small public building; second, this study intends to assist in achieving the LGCC objective of reducing the GHG emissions by 30% by 2020 and by 50% by 2050 when compared with the emissions registered in 2000.

Because no “baseline data” were available to allow comparisons, it was not possible to determine whether the estimated energy efficiency was good; however, this walk-through assessment served to define the baseline data, and provided a benchmark based on which the future progress can be measured. It will then be possible to accurately determine whether the objective of the LGCC is being satisfied by this building. However, the energy audits should serve to provide knowledge about the manner in which energy is actually being consumed [38].

The Ishikawa diagram in Figure 6 denotes the leading causes, classified into three groups, of energy wastage in the audited building. First, the most significant energy wastage occurs because of the building occupants/users. For instance, air conditioners were reported to be turned on in empty rooms in 15% of the reports. In 8% of the total reports, the doors were open when the air conditioners were turned on, and 11% of the reports referred to the usage of lighting in empty rooms. In the administration area, it was found a more inappropriate energy behavior when compared with those in other areas. These observations are consistent with those of previous studies, denoting that the occupants interact with the control systems to satisfy desired levels of personal comfort, and not energy efficiency [39]. This study also confirmed other findings, which reported that most of the energy wastage occurred during working hours [40]. Inappropriate behaviors, such as leaving lights and other appliances on after working hours, are more common than one may think, because they have also been reported in other studies [41].
Another element in the Ishikawa diagram denotes the infrastructure as a cause of energy wastage. Unfortunately, this is an old building that was designed without considering the energy performance. Currently, old buildings with energy-deficient structures are generating high energy costs in comparison with the new buildings that have implemented energy efficiency precepts [42]. Thus, the design and construction processes in buildings are essential for accomplishing the energy conservation objectives, because the energy efficiency strategies tend to be efficient if they are integrated from the beginning into the building’s construction process [43].

The audit of the infrastructure denoted that the building envelope components easily transfer heat from the exterior to the interior. The sides of the building were also not protected by the foliage. It was also found sources of heat infiltration/exfiltration in cracks in walls and doors, broken glass, poorly sealed windows, as well as some broken pieces in the ceiling or absence of soffits. The last spine in the diagram shows the equipment and electrical installations. During the audit, there were detected the air conditioners and electrical appliance in bad conditions, such as vibrating or being very noisy, and some exhibited damage to the chassis. Further, melted, burned and loose wirings were also identified.

![Ishikawa Diagram](image)

**Figure 6.** Ishikawa diagram for the leading causes of energy wastage.

Often, the retrofitting of old buildings involves the usage of an energy-saving technology [44]; however, the owners are reluctant to make structural changes to the building envelopes (Wilson 2015), most likely because the measures to retrofit the building envelope are expensive and economically inconvenient [45]. Therefore, it is more common to support energy-saving interventions that require no cost or result in cheap investments [46].

The public ownership status of the building affects energy efficiency, because most of the activities to save energy depend on external factors. For instance, maintenance of equipment or retrofitting depends on a public budget that many times is lack of it is never allocated. Most of the times, building users do not consider the saving of energy part of their duties. These situations are less likely to happen in private ownership because usually energy costs are considered as a key element of the total expenses.

Although investment is desirable for building retrofits, Mexico is currently intending to reduce public spending, making it impossible to invest in retrofitting technology, at least in the short term. Regardless, the audit report included a portfolio of potential alternatives for solving each of the causes mentioned in the Ishikawa diagram. User behaviors accounted for about 16% of the total energy wastage. Although this is less than the energy wastage from the wastage due to heat infiltration/exfiltration, the cost–benefit relation justified the appointment of an energy supervisor.
After screening several options, the high administration of CEDES decided to increase the building energy performance by hiring an energy supervisor to continue auditing and monitoring the energy efficiency performance of this public building. The development of an internal phone application to accelerate the reporting and corrective interventions was also suggested and approved. Further, the use of applications and software has proven to be successful in gathering data and understanding the energy-related occupant behaviors in buildings [47].

Energy auditors will be required along with an energy supervisor. It is usually recommended that the energy audits should be conducted by people well-versed with the technical aspects of auditing, allowing them to interpret and apply mechanisms concerning the demand, acquisition, transformation, and use of energy. However, the current energy audit has trained people from CEDES to conduct energy audits as a part of their daily activities.

Furthermore, the audit team was concerned about the sources of heat infiltration into the building and the impact that they can have on destabilizing the thermal control and increasing the energy consumption. After an exhaustive review of the available literature, it was learned that there is no consensus among experts regarding the magnitude of the problem despite the use of an air-infiltration modeling software. Even though airtight buildings exhibit superior energy efficiency performance, this condition can lead to poor indoor air quality and the breathing of stale air; therefore, it is necessary to ensure proper ventilation to remove the chemical pollutants, odors, humidity, and, mainly, accumulated carbon dioxide. This knowledge helped us to establish a factor for calculating the potential energy wastage instead of getting involved with the handling of the specialized modeling software. This method simplifies the audit for all stakeholders but mainly for those who participated in the audit report.

5. Conclusions

In summary, this study denoted that the energy audits can be useful for establishing a baseline or benchmark in situations in which previous data were not available to allow comparisons. Also, and perhaps more importantly, the energy audit identified opportunities to increase the energy efficiency performance of an old building. This paper offers an approach to improve energy efficiency in buildings up to 8% with a few steps to consider. Which is very valuable for building owners with minimal resources and investment.

The building envelope was a serious issue in case of this old building because of the high amount of heat transfer from the exterior to the interior, preventing optimal energy performance because it imposed high heat transfer demands and the usage of air conditioners during various periods, increasing the energy consumption. However, retrofitting the building envelope is not technically or financially feasible in the short term.

Consequently, bioclimatic design principles, including the orientation and shape of the building, vegetation, energy-efficient envelope, and energy-efficient appliances, should be considered and emphasized while planning the construction of new buildings.

It was found the behaviors of the occupants to be the primary source of energy wastage. Therefore, efforts should be made to raise awareness about the need to preserve the environment and natural resources by decreasing the energy wastage. Based on the results of the energy audit, it can conclude that a customized energy awareness program is essential. This program should encourage the occupants to change their behaviors and eliminate bad habits, including leaving doors and windows open when the air conditioners are on, adjusting thermostats according to particular preferences, or not turning the lights off when leaving an office. This audit was also useful for detecting equipment and electrical installation failures as well as for identifying maintenance requirements. An energy supervisor will be a key figure in leading the awareness efforts concerning empowering the occupants to behave according to the sustainability principles and also to strengthen and facilitate actual efforts for increasing the energy efficiency of this audited building and other public buildings.

Based on the case study discussed here, the CEDES personnel have gained the necessary knowledge to conduct energy audits in other buildings in the Ecological Center of Sonora as well as
other public buildings in the State of Sonora. Consequently, the Sonoran government is in a better position to assist to Mexican federal government in reaching the LGCC objective of reducing the GHG emissions by 30% by 2020 and by 50% by 2050 when compared with those registered in 2000.

**Author Contributions:** N.M. and L.V. conceived the present study and led the design of the study, the gathering, and computation of supervising the findings of this work and led the writing of this manuscript. J. E contributed to the supervision of the conclusions of this work and the writing of this manuscript. J.H and J.G.R. participated in the gathering of data. H.G participated in the analysis of data. All authors discussed the results and contributed to the final manuscript.

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