Academic buildings as a substantial part of the teaching system. The case of the new building design at the School of Engineering, National University of Rosario, Argentina

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Abstract. The population growth observed in the past decades demands that future buildings will have to include energy-efficiency measures as well as their own clean energy production plant, in order to be of very low or, if possible, positive net energy. This means that buildings will produce, on an annual basis, more energy than they will consume. The design of the new building for the School of Engineering, Faculty of Exact Sciences, Engineering and Surveying, National University of Rosario, Argentina, is given as an example of this kind of building. The building techniques applied in this design include: autoclaved aerated concrete in walls and insulation thermal roof panels, high energy and water consumption efficiency, photovoltaic power supply and sensors/dataloggers and actuators placed in the main equipment and sites. With these technological improvements, several analyses yielded reductions of 70%, in comparison with conventional buildings. Regarding the energy consumption of the facility, this is estimated at 29620 KWh/year, resulting in an energy intensity of about 25.7 KWh/(m²year). The energy annually produced by the PV plant (58491 KWh/year) exceeds what is required, which makes the facility a positive energy building in +49.4%, being this surplus exported to the National Electrical Interconnected System. The positive (clean) energy building implies that it avoids the emission to the atmosphere of a given quantity of greenhouse gases, in the present case 20647 TnCO2eq. In this way, through a comprehensive design of buildings, the construction sector can collaborate on the global contamination reduction and, consequently, global warming mitigation.

1. Introduction
The main objective of this work is to develop an optimal alternative for extending the building of the Faculty according to energy saving criteria, considering available constructive and technological aspects, as well as quality requirement.

A complementary intention is to accomplish proper liveability conditions, allowing greater comfort for those who will inhabit this establishment.
The 1151-square-metres extension will be used for educational and research purposes, as it will contain both laboratories and classrooms. A warehouse and equipped restrooms will also be included in this extension.

It is estimated that 130 occupants will use these facilities daily.

2. Project considerations

There exist several constrains to this project according to a previous architectural design which must be respected. These considerations involve location, orientation (11 degrees azimuth), architectural design, rooms’ arrangement and standards hygrothermal requirement.

The thermal behaviour and energy use of the construction were evaluated through RETScreen — a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis, as well as ongoing energy performance analysis.

One of the main hypotheses laid out in this study is the consideration of the interface between the existing building and the extension as adiabatic.

3. Constructive proposals

The materiality of the construction is a crucial aspect in the design of the building as part of the energy-efficiency measures required. An evaluation of several materials was conducted in order to analyse their main characteristics such as thermal behaviour, U-value, cost and availability.

The envelope of the building was studied in separate parts, these being external walls, roof and windows, thereby analysing optimal conditions for each. Geometrical properties and thermal transmittance were required in this evaluation through RETScreen.

3.1. External walls

For the realisation of external walls, the constructive techniques studied were steel frame and autoclaved aerated concrete brick wall, discarding conventional masonry for its poor insulation quality.

The steel frame technique has major advantages compared to conventional masonry, these being shortened period of execution of works, excellent acoustic comfort, high durability, good thermal insulation and low maintenance. These are all desirable characteristics when constructing a building with academic purposes. Nevertheless, steel frame walls do not have a U-value low enough for achieving positive net energy buildings; according to INCOSE – Argentina’s dry construction institute-, steel frame walls may reach a U-value of around 0.45 W/m²K [1].

Autoclaved aerated concrete (AAC) bricks also have advantages regarding efficiency in construction - it takes only 8 bricks to build 1 m² of wall- and physical properties that result in excellent thermal insulation and acoustic comfort, as well as waterproofing and fire resistance. In this case, a wall composed of 25-centimetre-thick ACC bricks, one additional insulation layer composed of a 7-centimetre-thick glass wool panel, finished with light aggregate plaster in the exterior and drywall in the inside, reaches a U-value of around 0.21 W/m²K (see for example: http://www.ecorex.in/product_aacblocks ). Considering that this technique involves fewer component layers, compared to steel frame walls - which include a vapour barrier, expanded polystyrene, oriented strand boards and glass wool, among others- and accomplishes a reduced U-value, an AAC brick wall becomes a more appropriate solution.

Additionally, the production of AAC bricks is a thriving industry in the Rosario area; this leads to a wide spectrum of providers, and, consequently, better offers.
3.2. Roof
Geometrical and architectural constraints led to propose a modular system of self-supporting insulation thermal panels affixed to a metallic structure. This configuration fits the preliminary design of the extension of the Faculty’s building.

Regarding the PV panels to be installed in the roof of the building, a study has been carried out to use the pre-established inclination (38 degrees) of the northern face of the roof as direct support for the PV panels. This slope is acceptable for the installation of PV panels in the roof. Moreover, this solution allows a major cost-saving in the metallic support structure required to adequately position the panels.

A 20-centimetre-thick roof panel of this characteristics supports as much as 300 kg/m² with a maximum clearance between supports of 3 metres. This provides an excellent surface for sustaining the PV panels. In addition, these roof panels reach a U-value of 0.185 W/m²K, offering good insulation.

3.3. Windows
Being most of the window panes facing south—and consequently not receiving direct sunlight throughout the year—the most desired property for these is a minimum U-value. A colourless double glazing has been selected for this matter, with a U-value of 1.8 W/m²K and a visible light transmission of 75%, which allows good natural illumination.

The solar factor for this type of window reaches a value of 0.64; this value is not determinant as windows facing south do not receive any infrared radiation. Also, this solar factor respects maximum solar exposure factor (0.90) determined by municipal ordinance 8757 (Rosario).

4. Water efficiency measures
Water efficiency measures have been included in the design of the extension in order to reduce potable water use as much as possible.

The proposed restroom toilets are high-efficiency toilets that only consume 3 litres per flush. In addition, dry urinals have also been proposed. These two measures allow a reduction in water consumption of 3000 litres per day as the use of conventional urinals and toilets would imply a consumption of 4000 litres per day—considering an average flush volume of 12 litres for these artefacts.

A grey water treatment has been planned; this system recycles water coming from restroom sinks and then uses the recycled water as supply for restroom toilets. It is estimated that 198 litres can be recycled everyday by pumping the grey water through a process that include filters—a coarse particle filter and then a finer particle filter—, fast-acting chlorine dioxide-based disinfectants and UV light disinfection. Since water required for toilet flush is predicted to be 1000 litres per day, the remaining water required is obtained by pumping well water to the toilets when recycled water is insufficient. This water management ensures zero consumption of potable water in sanitation.

Rainwater collection has also been considered since recoverable rainwater volume is approximately 690 m³ a year, considering the whole roof area. This water will be stored in a proper container and it will be used for cleaning and watering.

5. Heating and cooling system
The air-conditioning system is an essential aspect of the building design because of its high influence in energy consumption, it is mandatory to implement energy-efficient renewable energy equipment.
Geothermal and aerothermal energy air-conditioning systems were evaluated. They are both composed of a heat pump and a heat exchanger reversible system, which makes them usable for both heating and cooling, in accordance with interior comfort conditions.

Through the application of RETScreen software it was determined that geothermal energy air-conditioning system consumes around 50% less energy than aerothermal. This result led to the selection of a geothermal system. This system is based on vertically or horizontally buried pipes in which an anti-freeze solution exchanges heat with the ground. In winter, this fluid carries heat from the earth into the building and the other way around in summer.

An underfloor heating system for heating or fan coils for either cooling or heating can be used to condition the building atmosphere. Considering warm air gets up because of its lower density and ceiling height exceeds 7 metres, implementation of fan coils for heating would cause hot areas at the top of the rooms and cold areas at the workspace, resulting in uncomfortable conditions and an unnecessary waste of energy. Because of this, it was decided to install underfloor heating for heating and fan coils for cooling.

The air-conditioning system energy consumption was obtained from RETScreen software and it was about 18000KWh/year.

6. High efficiency equipment
Minimum energy consumption is a critical point in the design of an energy-plus building. An adequate selection of the equipment and an optimal use of these are both key issues to achieve that objective.

High efficiency devices were selected through a search in the local market.

6.1 Lights
The energy-efficient equipment selected includes 40W LED luminaire for laboratories; 20W LED luminaire for warehouse, restrooms and circulation spaces; and laptops -replacing desktop computers-.

The number of artefacts were calculated considering the surface and the necessary lighting level of the different room/spaces and lamp lighting area. Table 1 shows the number of lamps per sector and their respective operating time.

| Surface (m²) | Lighting level required (lux) | Lamp power (W) | Lamp lighting area (m²) | Number of Lamps (n) | Daily use (h) |
|-------------|-------------------------------|--------------|---------------------|-------------------|-------------|
| Laboratories | 145                           | 400          | 40                  | 3                 | 86a         | 8           |
| Restrooms   | 24                            | 210          | 20                  | 3                 | 8           | 12          |
| Warehouse   | 74                            | 210          | 20                  | 4.2               | 18          | 0.8         |
| Circulation| 155                           | 210          | 20                  | 4.2               | 37          | 0.4         |

*aThe number of lamps is greater than calculated as lamp arrangement is proposed in accordance with workspace distribution.

6.2 Sensors
Motion sensors and photocells will be installed in restrooms and circulation space to reduce the time use of lights.
6.3 Computers
An amount of 132 22-watt power laptops was considered in this analysis. These computers will only use energy for charging, considering an average charging time of 4 hours a day per laptop.

7. PV Plant
7.1 Energy consumption
Since the facility will be an energy-plus building, it is necessary to locally generate more energy than the total annual energy consumption.

The annual consumption is obtained considering the different artefacts and equipment which have been described in previous sections. The establishment—existing building and extension—operates from Monday to Friday, totalling 261 days a year. Moreover, a reduction factor of 0.7 was applied to lights and laptops energy consumption considering their use will not be simultaneous. Table 2 shows estimated daily energy consumption for the building.

| Daily energy consumption | Wh/d |
|--------------------------|------|
| Lights                   | 19872|
| Laptops                  | 8131 |
| Air-conditioning system  | 68966|
| Water system\(^a\)       | 16500|
| Total                    | 113469|

\(^a\)Grey water treatment, toilette distribution pumps and groundwater pump.

As a result, annual energy consumption is about 29620 KWh/year and energy intensity 25.7 KWh/(m²/year).

These values were obtained based on a theoretical analysis. Energy consumption must be monitored once the building is constructed and regularly operating.

7.2 Panels placement and shadow analysis
Available roof space without shadow throughout the year was analysed, resulting in northern and flat faces of the structure as usable support surfaces as shown in figure 1.

As previously mentioned, northern face inclination angle is 38 degrees and in winter solstice, the incident angle of sunlight is 34 degrees. Given these conditions, the modular roof structure casts a shadow to the followed northern faces, reducing the available area as shown in figure 1. The 136 selected panels with dimensions of 992 mm x 1956 mm will be arranged in the building roof (see figure 1).
7.3 PV plant design of the positive energy building and avoided greenhouse gases emissions

The PV plant was designed with 136 PV panels of 330 W each one, that cover a roof surface of 272 m², having a total solar photovoltaic power of $W_{\text{total,peak}} = 45 \text{ KWp}$. The annually produced electricity can be obtained applying the following formula:

$$E_{PV} = PV_{\text{OUT}} \cdot W_{\text{total,peak}} = 66467 \text{ [KWh/year]}$$

where $PV_{\text{OUT}}(X, \phi, \beta)$ is the merit factor of the photovoltaic power plant, a ratio between the electric energy that can be produced annually for each KW peak of PV power installed at a given geographical site X and given azimuth ($\phi$) and inclination ($\beta$) angles. For Rosario, Argentina, the Global Solar Atlas (available at the web page of the World Bank Group: https://globalsolaratlas.info) determines a value: $PV_{\text{OUT}}(\text{Rosario}, 11^\circ, 38^\circ)=1481 \text{ KWh/year}/\text{KWpeak}$.

Taking into account the losses of the system as 12%, due to inverter, internal transmission lines, DC/AC transformation, mean soot deposition, etc, the electricity annually produced will be $E_{PV}' = 58491 \text{ MWh/year}$.

Since the annual energy consumption of the building was determined in item 7.1 as: 29620 KWh/year, the proposed solar PV power plant will provide 49.4 % more energy than it will be used in a year, the rest will be exported to the National Electrical Interconnected System (NEIS). We like to point out that, since the building do not include electric charge accumulators (i.e., batteries, inertial systems, supercapacitors), it also receive energy from NEIS, when the PV power plant do not provide enough energy, but the net annual result corresponds to a positive energy building (see for example: Melnyk [2] and Thyholt et al.[3]).

The reduction in the emission of greenhouse gases (GHG) can be obtained from the coefficient that converts a unit of mixed electric energy (renewable and non-renewable) of the Argentina national electric system and a unit of emitted GHG, which is: $f_{E,\text{GHG(Argentina)}}=0.353 \text{ TnCO2eq/MWh}$ (as reported recently by the Secretary of Energy of Argentina). Therefore, the annual mass of avoided emissions is:

$$M_{\text{GHG,FV}} = f_{E,\text{GHG(Argentina)}} \cdot E_{PV}' = 20647 \text{ TnCO2eq/year}$$

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*Figure 1. Shadows analysis at roof structure. PV: solar panel placement*
In conclusion, the proposed system (besides to provide renewable energy and to permit to make research) will contribute to the training of university students in the global effort to mitigate global warming [4].

7.4 Energy consumption comparison with conventional construction

Replicating lighting, occupancy, location and comfort conditions, the annual energy consumption of a conventional construction was calculated. Conventional construction refers to the use of non-energy-efficient illumination system, desktop computers, traditional envelope materials and roof top air-conditioning system. No water treatment was considered. Energy consumption breakdown is shown in table 3.

| Table 3. Conventional case daily energy consumption |
|-----------------------------------------|
| Daily energy consumption (Wh/d)       |
| Lights              | 49879         |
| Desktop computers | 155971        |
| Air-conditioning system | 167816   |
| Water system*a   | 1             |
| **Total**                | **373667**   |

*aToilette distribution pumps.

As a result, annual energy consumption is about 97527 KWh/year and energy intensity 84.7 KWh/(m²/year), over 3 times more than the 29620 KWh/year consumption estimated in the proposed design (corresponding to a 70% reduction for the new design).

8. Discussions

The energy intensity achieved for the building design is satisfactory when comparing with said parameter of a conventional construction building. Even though the major impact on energy consumption is due to the air-conditioning system. Also, high-efficiency lighting allows a significant reduction of 60% with minimal investment. This result emphasizes the need of including energy-efficient lighting as a must in all existing and future buildings.

Another major reduction is obtained when using portable computers as opposed to desktop computers. This outcome indicates the need to expand the use of laptops in offices and institutions, considering that nowadays these devices have both excellent capacity and performance.

Adequate building techniques are substantial for an optimal behaviour of the building with its environment. Proper insulation qualities allow a reduction in energy consumption for heating and cooling, as well as provide better comfort conditions for occupants.

On the other hand, pre-established architectural design of the building represented a major constraint when pursuing an energy-plus building design, mainly because of its large South-facing windowpanes and high ceiling rooms. However, these limitations were successfully resolved, proving that with correct analysis and design, larger energy savings can be exploited.

Nevertheless, the pre-established design of the roof resulted in a good use of the structure as a direct support for the PV panels. This points out that architectural design must not only be considered for orientation and window distribution purposes, but it should also include appropriate conditions for energy generation through renewable sources.
Regarding water saving, results obtained evidence the need of evolution towards more efficient sanitation facilities, in order to reduce the consumption of both potable and non-potable water. Furthermore, rainwater harvesting allows a significant reduction in water use for cleaning and watering, with a very low investment and simple installation.

Points of improvement include lowering the ceiling in rooms to accomplish greater efficiency in their heating and cooling; reducing the glazed surfaces to improve insulation, and the installation of magnetic induction lamps which consume less energy than LED lamps and have a longer life span.

Moreover, ongoing monitoring systems must be applied to control water and energy use, as well as comfort conditions, in order to assess and improve the performance of the building through an energy management system, such as ISO 50000 series (or in Argentina, IRAM 50001). This monitoring system not only allows continuous improvement, but also allows students and professionals to analyze/investigate measurable variables and indicators of the building, enriching their vocational training and activities.

9. Conclusions
Today, professionals have the rising responsibility of designing and executing constructions that satisfy the needs of clients and society and do not harm the environment. This requires a thorough study of all the factors involved, as well as full acknowledgement of the consequences of acts.

This study demonstrates that constructions can be environmentally friendly and must include an appropriate design, construction and operation; a lack of commitment to this end on the part of any participating actor could endanger this purpose.

The complexity in all stages of development is given by the multidisciplinary interventions required to attain the objective of Sustainable design. Additionally, countries like Argentina, struggle with misinformation and insufficient education in the proposed building techniques, which could result in the misuse of this kind of facility. Education is the main instrument to encourage the efficient and careful use of natural resources.

Moreover, in Argentina, energy-efficient building materials are in early development and their dissemination is poor. Nevertheless, it has been proven in this study that the offer of better-quality materials exists and so the construction techniques involved.

To conclude, Sustainable construction is feasible if all participant actors work together towards this objective from the conception of the project to its operation. Sustainable design does not limit constructions but empowers them.

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