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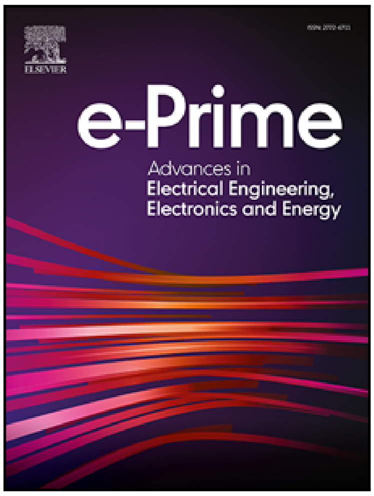

Model for the implementation of strategies for the solar energy use in a healthcare network

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Highlights

- The objective of this paper is to introduce a model for strategies for solar energy use implementation in a healthcare network.
- 10 hospital buildings located in the Micro-Region del Gran La Plata, Buenos Aires, Argentina, is adopted as a case study.
- Based on the indexes developed, it was observed that potential hospitals are those located in peripheral areas.
- Linking critical fuel consumption values with solar radiation in the building envelope made it possible to detect suitable sectors for the installation of PVS on roofs and STS on north façades.
- In Argentina, state-subsidized energy and technology costs present an economic barrier to project implementation for hospital managers.

Model for the implementation of strategies for the solar energy use in a healthcare network

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Keywords: Hospitals, Energy management, Solar energy, Health sector, Renewable energies

Abstract

The implementation of strategies for solar energy use (SSEU) such as photovoltaic (PVS) and solar thermal systems (STS) in hospitals are alternatives for reducing conventional fuels consumption and CO_2 emissions of energy-intensive buildings. However, there are barriers to the deployment of renewable energies in such buildings, which focus on technology costs and economic inventiveness. Thus, there is a need for tools that address the particularities of hospitals and that can provide new information to management authorities for the development of sustainable policies. The objective of this paper is to introduce a model for SSEU implementation in a healthcare network. For this purpose, a workflow is presented that allows the analysis of 3 levels in the health sector (healthcare network, hospital, and pavilion), where the aim is to: i. Identify hospitals with solar potential in a healthcare network, ii. Sectorize suitable surfaces in potential hospitals for SSEU implementation and iii. Determine the architectural, environmental, and economic feasibility of technologies. In this case, a healthcare network located in Micro-Región del Gran La Plata (Argentina) is selected as a case study. Based on the indexes developed, it was observed that potential hospitals are those located in peripheral areas. Then, linking critical fuel consumption values with solar radiation in the building envelope made it possible to detect suitable sectors for the installation of PVS on roofs and STS on north façades. Finally, state-subsidized energy and technology costs present an economic barrier

to project implementation for hospital managers. However, by shifting the subsidy to the purchase of technologies, viable results could be achieved.

1. Introduction

Energy management in buildings is now emerging as a significant issue in addressing sustainable development objectives, as buildings are responsible for 40% of total energy consumption, approximately [1–3]. In order to regulate the use of fossil fuels and to find other environmentally friendly ways, harnessing solar energy provides an alternative to conventional sources. It is clean, cheap and available in abundance throughout the year [4,5]. However, the solar energy industry faces challenges such as high capital costs, dependence on environmental conditions and complicated operations and maintenance [6]. Therefore, it is necessary to develop methods to optimize resources by considering the interaction between the outdoor environment and buildings.

Understanding that hospitals are energy-intensive buildings [7–9] and play a very crucial role in our societies [10–12], the implementation of strategies for solar energy use (SSEU) in these buildings would contribute to reducing the consumption of conventional sources and greenhouse gases (GHG) emissions, as well as improving the quality of public spaces. In the case of health buildings located in remote areas, this effect is even more relevant, since, in addition to the above, the dependence on a hydrocarbon transport service is reduced [13,14]. Likewise, hospitals need to guarantee the continuous operation of their equipment [15], so that, in the event of blackouts, photovoltaic systems (PVS) equipped with battery banks can be a complement to diesel generators. Finally, hospitals offer extensive surfaces for the installation of SSEU. Both on façades and roofs there is usually space for the incorporation of active and/or passive systems. In this way, there are several studies verifying the benefits of SSEU in hospitals.

The study by Calderón Menéndez [16] shows that including 50 photovoltaic panels (12.5 kW) in a sanitary building in El Salvador allows covering 77% of the annual electricity demand, with a payback period of 5 years. Other more ambitious projects, such as those of Kassem et al. [17], are looking at the incorporation of 10,479 photovoltaic panels of different types and inclinations in a 209-bed hospital in Cyprus. With an output of 1,789 kW, the proposed PVS covers the annual demand, except for the months of January, December, and July, with an expected return on investment of around 7 years. Other studies combine multiple strategies, including integrating solar thermal systems (STS) and PVS in the same building. The study of Pop et al. [18] evaluates the effects of 119 thermal collectors and 157 photovoltaic panels in a municipal hospital in Sighetu Marmaţiei, in the northern part of Romania. The results show that the STS would cover 35% of the annual domestic hot water (DHW) consumption, while the PVS would cover 5% of the annual consumption of the fans.

However, there are barriers to SSEU deployment, especially in developing countries. The main one is the lack of economic incentives for the implementation of technologies [19–21]. Thus, there is a lack of diagnosis tools for the application of solar energy technologies in the health sector, either for electrical and/or thermal use. Therefore, by studying solar radiation on a city and its buildings at different scales, new information can be provided to inform policy making for the deployment of renewable energies. For this reason, the objective of current paper is to present a model for the implementation of SSEU in a healthcare network. The aim is to offer a platform that provides information to facilitate decision-making by management authorities. In this respect, numerous methods have been developed in recent years to analyze the harnessing of solar energy, most of them focusing on a set of buildings or sectors of a city.

In the case of models to analyses solar radiation in urban blocks, there are recent studies focusing on residential [22] and commercial buildings [23], both of which propose a design decision-making framework for the siting of PVS. These studies use a genetic algorithm developed in Rhinoceros3D-Grasshopper [24] which aims to find optimal solutions to the multi-objective problem. In this way, it allows finding the best configuration of photovoltaic panels considering their orientation and the number of panels that satisfies the constraint of not exceeding a payback period specified by the user. Along the same lines are studies such as Zhang et al. [25], which analyses characteristic city blocks in Singapore, allowing the morphology and organization of the units to be reconsidered for future construction. The authors use a workflow framework, where they integrate different energy performance indexes, and combine different prefigured models of urban blocks, allowing to detect the differences between the proposed alternatives. Similarly, study of Choi et al. [26], based on the Shinagawa waterfront redevelopment, uses different proposals to determine the one that generates the highest energy production from PVS. Including existing (commercial) buildings, the authors evaluate different scenarios, where the morphology of the buildings varies, and the floor area remains constant.

Another work focused on the residential sector, but in a city scale, is that of Chévez et al. [27], which seeks to identify potential urban sectors for the incorporation of solar systems, both active and passive. By elaborating indexes where energy and social variables interact, the authors sectorize the city into homogeneous areas and, at a lower scale, into urban mosaics. In this way, policies could be developed to facilitate the introduction of SSEU in the identified sectors. Continuing on the city scale, Wegertseder et al. [28] proposes a model that evaluates the solar resource and the integration of solar energy into the energy system. The first stage comprises a step-by-step approach starting with a global temporal pattern of solar radiation to which urban and building spatial topologies are linked to assess solar losses. It then uses the results of the solar resource model, inputting building-specific solar energy data at the energy system level, considering the energy infrastructure, finally obtaining an estimate of the usable solar potential in a city. Lastly, at this scale, one can also find works such as those by Qerimi et al. [29], which analyses the solar potential in the city of Pristine (Kosovo) to determine the thermal energy that can be saved through solar energy. By applying a methodology that goes from the macro to the micro scale, the authors estimate DHW production from STS for different types of buildings using TSOL 2018 software [30].

A barrier that exists in certain energy management tools is their user-friendliness, this is the case of work where models are made from a textual programming language [31]. Another frequent problem in studies that analyze different buildings (commercial and residential) together is that hospitals have a demand profile that differs significantly from buildings with different programs. Hospital buildings operate at full capacity 24 hours a day [32] and therefore need to be disaggregated for study purposes. In addition, the health sector is interpreted as a set of networks [33] and not from a zonal perspective, as is the case for residential buildings [34]. According to Discoli [35] the nodes (hospitals) that compose them are linked by some formal or informal hierarchical order of complexities. Based on this conception, comprehensive projects are carried out between institutions with the same dependence and source of financing, such as the remodeling of emergency rooms or the expansion of surface area of public hospitals in a municipality.

Indeed, there are few studies at the hospital network level. The work of Carbonari et al. [36] provides a method to assess the feasibility of retrofitting strategies in three acute hospitals and two community clinics located in Italy. In this study, an integrative evaluation of several alternatives for energy efficiency is presented, showing effects on the five buildings. In this regard, recent work addressing solar potential in various hospital networks is that of Sánchez-Barroso et al. [37]. The paper provides a methodology to calculate the potential energy savings from the incorporation of STS in different hospital networks in Spain. The authors use a solar fraction considering the number of systems to be installed in each hospital's floor space. Finally, the work of Discoli [38] provides a methodology for an early diagnosis of a public sector hospital network. By introducing energy, technical-constructive and productive-sanitary variables, it is possible to observe different energy performance profiles at the network scale. Although these works address the energy problem from a hospital network, they lack the analysis to detect the solar potential. While work of Sánchez-Barroso et al. [37] offers such a search, it does not delve into other levels of analysis, without considering the possible evaluation of different technologies, for example, which could be a later step. On the other hand, the authors only focus on STS, closing the methodology by not considering the possible combination with PVS.

In view of the need to generate tools to promote the deployment of renewable energies in the health sector, different works related to the study of the possible use of solar energy on a city scale, urban block and hospital network were analyzed. The contributions focus on the use of specific software, both for the analysis of energy performance and for the performance of SSEU. Thus, from the reviewed works, a macro to micro approach is adopted, which allows integrated results to be conceived from supra-unit levels. Finally, the idea of linking productive-health and energy variables for the formulation of evaluation index is taken. Thus, the scope of these studies shows that, in some of them, the processes for obtaining data are complex so that the methodology can be replicated by non-specialized professionals. Then, it is highlighted that hospital buildings should be analyzed separately because they have unique consumption profiles and carry out management processes in the form of a network. Finally, studies on hospital networks lack a multi-level approach and focus on a single type of solar energy conversion (thermal).

Based on the above, the research focuses on answering three questions: Which hospitals are most capable of harnessing solar energy? Which sectors are suitable for implementing SSEU? and how many systems and what kind of technologies should be used?

2. Methodology

To answer the above questions, a workflow model is developed that addresses 3 levels of analysis within the health sector and achieves the following specific objectives:

- Identify hospital buildings with solar potential in a healthcare network.
- Sectorize suitable surfaces in potential hospitals for SSEU implementation.
- Determine the architectural, environmental, and economic feasibility of technologies.

The first stage consists of classifying the hospitals belonging to the same network according to their solar potential. To do this, we start at the level of analysis at the building scale (hospital building), and obtain the productive-sanitary, morphological, territorial and energy performance variables. With these values and considering a priority (replacing conventional sources or injecting electricity into the grid), solar indexes are constructed, which will define the solar potential. The results are then reintegrated into the healthcare network level of analysis. In the second stage, we return to the (potential) hospital level of analysis to assign sectors to SSEU. Thus, by determining a critical consumption of a certain fuel and analyzing the solar radiation on the hospital surface, ideal sectors are assigned to different SSEUs. Finally, the third stage consists of analyzing different technologies to identify the most viable one. This is done by proceeding to the pavilion level of analysis and evaluating the technologies and their location in terms of integration with the architectural design, fossil fuels and GHG emissions savings and economic feasibility. The Fig. 1 shows the workflow model developed.

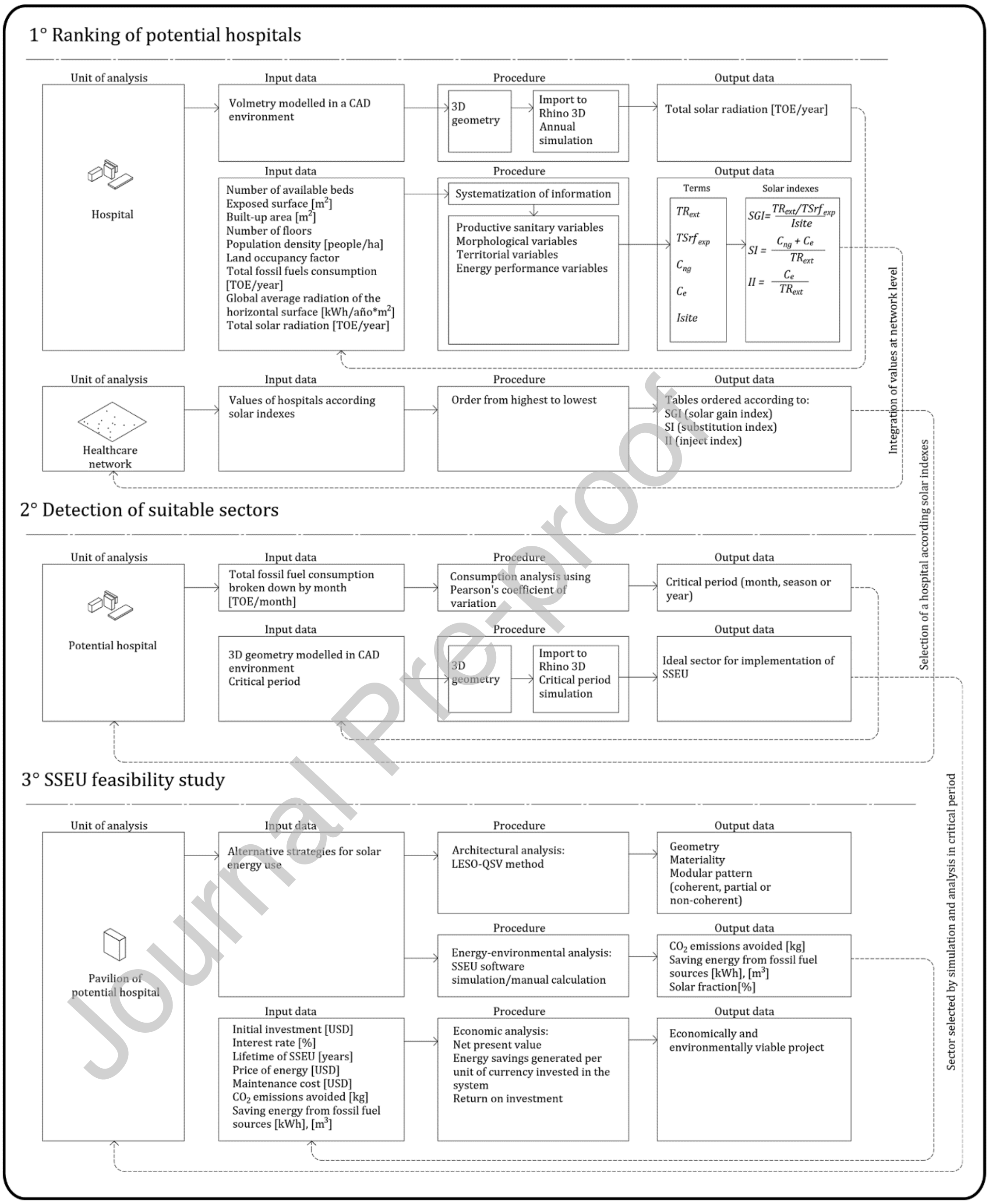


Fig. 1. Workflow model developed

2.1. Ranking of potential hospitals

For the ranking of hospitals, in the first instance, those that are linked by some formal or informal order of complexities should be selected. Hospital buildings that share a common source of financing and authorities should be adopted. In this way, the management carried out in the selected group is consistent with an organizational structure of the health system (public subsystem or private subsystem). Subsequently, based on the characterization according to relevant variables and the subsequent obtaining of solar indexes, an attribute is assigned to compare the potential of the hospitals in the same healthcare network.

2.1.1. Determination of total radiation per hospital

First, the solar radiation captured by the exposed surface of each hospital is required. For this purpose, the Rhinoceros3D-Grasshopper software is used. Based on the modelling of the geometries of the hospitals and their respective environments, in Rhinoceros3D (Rhino) or in another computer-aided design (CAD) software, a ".gh" file, executable in Rhino, is used to calculate the total radiation on the hospitals. In this case, the algorithm used is called HD-SARSE, is available at https://doi.org/10.17632/6hvwtnfk8v.6 (accessed 21/9/22) and has been used in other works to determine the solar potential in buildings with different geometries and environments [39,40].

2.1.2. Obtaining solar indexes

Subsequently, the following input data are required. For each hospital there should be: The geometry modelled in a CAD software, number of available beds, exposed surface area, built-up area, number of floors, population density, land occupancy factor (LOF), total fossil fuel consumption and total solar radiation (obtained from HD-SARSE). The value of available beds can be obtained from the website of the ministry of health in charge or from official sources in the case of the private sector. LOF is the relationship between the area of the lot covered by the hospital and the total area of the land. The result is obtained from the analysis of satellite images. Population density value allows estimating the number of people living in each sector of the city and can be obtained from the municipal urban planning codes. The exposed surface, the built-up area and number of floors can be obtained from the analysis of plans, which can be consulted in the technical area of each health building. The analysis of the same plans also provides the data for modelling the geometry of the hospital in CAD software. To determine the total consumption of energy from conventional sources, it is proposed that the meter of the different energy sources used should be read. If these data are not available, estimates should be based on audits or surveys.

Once the input values have been obtained, the hospital are characterized. To do this, the data collected are grouped into morphological, territorial, productive-sanitary and energy performance variables. The characterization of the hospitals makes it possible to establish the attributes that determine which hospital offer the best conditions for the implementation of SSEU, it is proposed to develop indexes to be applied to each hospital. Furthermore, the systematization of the variables will make it possible to establish hypotheses on the factors that influence the collection of solar energy.

The following indexes should be calculated for each hospital:

- Solar gain index
- Substitution index
- Injection index

To define the potential of a specific building to capture solar energy on its exposed surface, in this study it is proposed to use an indicator that evaluates the geometry and environment of the hospital in relation to the solar radiation on its façades and roofs (Eq. 1).

$$SGI = \frac{TR_{ext}/TSrf_{exp}}{Isite} \qquad \textit{Eq. 1}$$

Where SGI is the solar gain index; TR_{ext} is total annual solar radiation on the outdoor area of a hospital (value obtained by applying HD-SARSE), expressed in [kWh/year]; $TSrf_{exp}$ is the total exposed surfaces of a hospital, expressed in [m^2] and Isite is annual global solar irradiance on the horizontal plane where the hospital is located, expressed in [kWh/m^2*year] (based on data provided by [41]).

To define the potential of a given hospital to substitute energy from conventional sources with solar energy collection, it is proposed to use an index that evaluates TR_{ext} and energy consumed from conventional sources (Eq. 2).

$$SI = \frac{C_e + C_{ng}}{TR_{ext}} \qquad \textit{Eq. 2}$$

Where SI is substitution index; TR_{ext} is total annual solar radiation on the exterior surface of a hospital (value obtained by simulation in Rhino), expressed in [kWh/year]; C_e is annual electricity consumption, expressed in [kWh/year] and C_{ng} is annual natural gas consumption.

Finally, to define the potential of a given hospital to inject electricity into the public grid from the solar energy it can capture, an index is proposed that evaluates the TR_{ext} and the consumption of electricity from the public grid (Eq. 3).

$$II = \frac{C_e}{TR_{ext}} \qquad \textit{Eq. 3}$$

Where II is injection index; TR_{ext} is total annual solar radiation on the outdoor area of a hospital (value obtained by applying HD-SARSE), expressed in [kWh/year] and C_e is annual consumption of electricity from the public grid, expressed in [kWh/year].

2.1.3. Identification of potential hospitals according to solar indexes

Once the indexes for each hospital have been obtained, they must be integrated into the healthcare network. In this way, by sorting the solar indexes from highest to lowest, we obtain a table with the most potential hospitals in terms of their ability to receive solar radiation on their exposed surface area, to substitute energy from fossil sources and to feed electricity into the grid.

2.2. Detection of suitable sectors

For the second step of the methodology, a hospital is selected according to the calculated indexes. Considering that there are several SSEU, and that they can provide both electric and thermal energy, it should be considered the possibility that hospital can incorporate PVS and STS in the same building. In this section, arguments are offered to determine the location of both measures through the detection of sectors with higher solar radiation in a period of higher energy consumption for a given source.

2.2.1. Determination of critical period

Once the hospitals have been ranked, the critical period to a given hospital must be identified. This is the season or month with the highest consumption of a given source over the course of a year. In fact, as a first input, it is necessary to have the annual consumption of conventional sources broken down by month. To select the (critical) period to adopt, either to inject energy or to substitute conventional sources, the following rule is used: when monthly consumptions are homogeneous, the annual period is taken, on the understanding that there is no month or season with considerable maximum values; and if monthly consumptions are heterogeneous, the monthly or seasonal period is taken, understanding that there is one or several more demanding months for a given source. Likewise, to identify whether the data are homogeneous or heterogeneous, Pearson's coefficient of variation (Eq. 4) is used, considering r < or = 25% as a homogeneous sample and r > 25% as a heterogeneous sample.

$$r = \frac{Sx}{\bar{x} * 100} \qquad \textit{Eq. 4}$$

Where r is Pearson's coefficient of variation, Sx is standard deviation of monthly energy consumptions and $\bar{x}$ is average monthly energy consumption.

2.2.2. Detection of suitable surface on 3D geometry

Subsequently, solar radiation simulations must be performed on the 3D geometry of the hospital based on the period selected. In this way, the areas with the highest values of solar irradiance in a period with the highest consumption of a particular fuel are identified. For example, suitable sectors are established in relation to the period with the highest electricity consumption for the location of PVS and/or in relation to the period with the highest natural gas consumption for the installation of STS.

In the first instance, the monthly values referred to the TR_{ext} and the energy consumption from conventional sources should be systematized in a database. HD-SARSE is used for this by entering the desired analysis period. It should be noted that the values obtained from the simulation arise from the evaluation of points on certain building surfaces (meshes). Thus, different values of solar irradiance can exist on a surface, differentiated graphically by a color scale (warm and cold), and analytically, expressed in [kWh/m^2].

In case the values are heterogeneous, for injection of electrical energy to the grid (the potential period, in this case) the difference between the values of monthly electricity consumption and the solar radiation values for each month is determined. The highest value is chosen, this being the month with the highest solar radiation capture and the lowest demand for electricity. In the case of substitution of energy from conventional sources, the critical period is determined from the maximum value of the monthly consumption of energy from conventional sources.

2.3. SSEU feasibility study

Finally, once the suitable sector has been defined, the feasibility of different SSEU should be studied based on various alternatives of both STS and PVS. In this regard, the strategies are compared along three dimensions:

- Architectural integration
- Fossil fuels and GHG emissions savings
- Economic performance

2.3.1. Architectural integration

To evaluate the integration of a given strategy with the architectural design, the LESO-QSV methodology (Laboratoire d'Energie SOlaire - Qualité- Sensibilité-Visibilité) is adopted, which promotes the use of solar energy while preserving the quality of pre-existing urban areas. This qualitative methodology provides a traffic light type rating to a given strategy, which can be found to be very coherent (green), partially coherent (yellow) or not coherent (red). Likewise, to differentiate between degrees of integration with the architectural design, the work of Munari Probst & Roecker [42] offers situations for each aspect to be considered, such as geometry, materiality and the modular pattern of the system to be incorporated. This provides a reference when it comes to establishing a qualification:

- To evaluate the geometry of the system to be implemented, the size of the collector field and its position must be considered. The more uniform the distribution of the elements of the system are, the more integrated it will be in the design.
- To evaluate the materiality, the visible materials of the collector field to be incorporated should be considered, as well as the color and textures of the surfaces. In this sense, the more similar the materiality of the system is to the existing ones, the more integrated it will be in the design.
- To assess the modular pattern of the system to be incorporated, the modulation of the collector field and its integration with the modulation of the existing building

components should be considered. The more similar the two modulations are, the more integrated it will be into the design.

To determine the integration to the architectural design, the sectors chosen to include SSEU are modelled in the SketchUP 2018 software [43], respecting building components, textures, and colors.

2.3.2. Fossil fuels and GHG emissions savings

After the incorporation of a given strategy, annual energy savings are observed, expressed in [kWh/year] in the case of electrical energy or in [m³/year] in the case of natural gas. This study focuses on STS strategies due to the criticality of the use of natural gas in the case study analyzed. For this reason, the calculation of savings in heating and DHW by means of STS is presented below.

To determine the heating savings from different STS, the TSOL 2021 software is used. This is a popular software [44] that provides the solar fraction, amount of CO_2 avoided, and fuel saved from the input of certain values. The inputs required to obtain the desired results are described in detail below.

The input data can be organized in 3 sections:

- Climate data
- Heat for heating
- Strategy components

The information entered in "Climate data" allows the program to calculate the global solar irradiance on the horizontal surface of a given site, as well as to define the outdoor temperature for the calculation of the thermal demand. For this purpose, the software has a climatic database provided by the Meteosyn platform [30].

In "Heat for heating", the required heating load (expressed in [kW]) must first be determined. Subsequently, the useful surface to be heated, the indoor ambient temperature, the standard outdoor temperature of the project and the heating limit temperature must be entered. The type of building envelope must also be selected from three options: lightweight building, semi-heavy building and heavy building.

On the other hand, the external heat access must be taken into account. For this purpose, the software requests the input of the transparent surface in relation to the surface to be heated. Also, the orientation and type of glass must be discriminated. In addition, the internal heat generated in the space to be heated (expressed in [W/m^2]) must be entered in this section. Finally, the period of operation of the heating system must be entered.

In "Strategy components", firstly, the type of installation to be used must be indicated. The software offers 71 alternatives, such as, for example, systems to provide DHW, to heat spaces, to heat a swimming pool or a combination of the above.

Secondly, the characteristics of the collector field must be defined, distinguishing conversion factor, gross collector area, inclination and orientation and the arrangement of the panels (vertical or horizontal).

The next step is to determine the auxiliary heating components, specifying the power of the auxiliary heating. Finally, the characteristics of the buffer tank (water storage tank) for heating must be specified, defining its storage capacity and insulating material.

For the calculation of DHW savings by means of STS, the daily consumption of the energy used for DHW, and the energy generated by the system to be implemented must be taken into account.

To determine the DHW savings generated from STS, the first step is to determine the consumption of natural gas generated by DHW (Eq. 5).

$$E_{gas}^{(daily)} = \frac{E_{useful}}{H} + E_{m24} \quad \textit{Eq. 5}$$

Where $E_{gas}^{(daily)}$ is natural gas consumption per day, expressed in [m^3/day]; H is equipment performance and E_{m24} is consumption by pilot light, expressed in [m^3/day]. In addition, Eq. 6 is adopted to calculate E_{useful}.

$$E_{useful} = m_{water} * Cp_{water} * \Delta_{t^\circ} \quad \textit{Eq. 6}$$

Where E_{useful} is energy consumption, expressed in [m^3/day]; m_{water} is water mass, expressed in [kg]; Cp_{water} is specific heat of water, expressed in [kcal/°C*kg] and Δ_{t° is thermal difference between incoming and outgoing water, expressed in [°C].

On the other hand, the energy generated from the specific SSEU must be known (Eq. 7). Due to the technical-constructive characteristics of certain buildings, the space for the incorporation of collectors may be limited. For this reason, generation is obtained from a defined number of solar collectors.

$$E_{gen} = n_{panel} * Pp_{panel} * PSH * \eta \quad \textit{Eq. 7}$$

Where E_{gen} is energy generated, expressed in [m^3/day]; n_{panel} is number of panels; Pp_{panel} is peak potential per panel, expressed in [kWp]; PSH is peak solar hours, expressed in [h/p] and η is performance system. For the calculation of PSH, they are obtained from Eq. 8.

$$PSH = Isite * \alpha * Los_{shad} \quad \textit{Eq. 8}$$

Where PSH is peaks solar hours, expressed in [h/p]; Isite is annual global solar irradiance on the horizontal plane where the hospital is located, expressed in [kWh/m^2*day]; α is correction by orientation; Los_{shad} is correction for shading losses.

2.3.3. Economic performance analysis

Economic analysis is one of the main tools to determine the implementation of SSEU. In this case, the net present value (NPV) is taken, which allows calculating the present value of a certain number of future cash flows, originated by an initial investment (Eq. 9); and the payback time (PBT) of the investment. In both operations, the use of different rates (0%-11%) is adopted [45]. In addition, two scenarios are proposed for this analysis: one where services are subsidized and the other where SSEU are subsidized. This aspect has an impact on system and energy costs, and different values have to be adopted depending on the scenario.

$$NPV = -I + \sum_{i=1}^{n} \frac{(Fi - Fo)}{(1+k)^t} \qquad \text{Eq. 9}$$

Where NPV is net present value, expressed in [USD]; I is Initial investment, expressed in [USD]; Fi is annual income flow, expressed in [USD/annual]; Fo is annual outcome flow, expressed in [USD/annual]; k is interest rate; t is period corresponding to the project year.

To determine the total cost of a given SSEU (I), values provided by local companies are used. Likewise, the values corresponding to the annual cash flow (Fi - Fo) are obtained from the maintenance costs (Fo), based on prices off companies in charge of monitoring equipment that use pumps; the annual energy savings (ES_{annual}), generated by the system used and the price of energy (P_{ener}). The latter depends on the stakeholder, being the value of the invoice, in case the investor is the authority of a given hospital (end-user), or the price of imported energy, in case it is a government authority (national, provincial, or municipal). In this way, Fo is annual maintenance cost and Fi is P_{ener}* ES_{annual}.

Understanding that energy costs and the technologies used in different SSEU depend on government policies; it is proposed to associate the stakeholder with the scenarios (with energy subsidy and with SSEU subsidy). Thus, in a scenario where policies are those of energy subsidy, the stakeholder will be that of the end-user (hospital authority). In this case, the price of energy will be the value of the bill (subsidized energy) and the cost of the SSEU will be that provided by local companies. On the other hand, if the scenario maintains policies for the development of renewable energy, the stakeholder will be the government authority. In this case, the price of importing energy and the cost provided by local companies will be adopted, applying the discount equivalent to the energy subsidy.

3. Case study

For the application of the methodology, the hospital network of the Micro-Región del Gran La Plata (MRGLP), which is made up by the districts of Berisso, Ensenada and La Plata, province of Buenos Aires (Argentina), was taken as a case study. It belongs to bioclimatic zone III, characterized as warm temperate, and to subzone IIIb, where thermal amplitudes throughout the year are small [46]. In terms of solar resources, the area under study has an annual solar irradiance value equal to 4.56 kW/m^2 per day [41], a value comparable to those of Spain (one of the best areas in Europe in terms of solar irradiation) [47]. Regarding its political-institutional organization, the hospital network under study is located in "Health Region XI" within the province of Buenos Aires, one of the areas with the largest number of health buildings [48].

3.1. MRGLP provincial hospital network

For the application of the first stage, the hospitals belonging to the healthcare network were georeferenced by means of a geographic information system (GIS), distinguishing between provincial and private hospitals. Based on the information obtained from the Argentine Integrated Health Information System [49], the coordinates of each building were obtained and the QGIS 3.2.2 software [50] was used to create the map shown in Fig. 2.

Due to limited access to information, the study was carried out on 10 of the 12 hospitals with provincial dependence, which are part of the public subsystem, that is, they belong to a system financed by general revenues and that provides medical care to all the inhabitants who require it [51]. The hospitals were also characterized according to productive-sanitary, morphological, territorial (**Error! Reference source not found.**) and energy performance (Table 2).

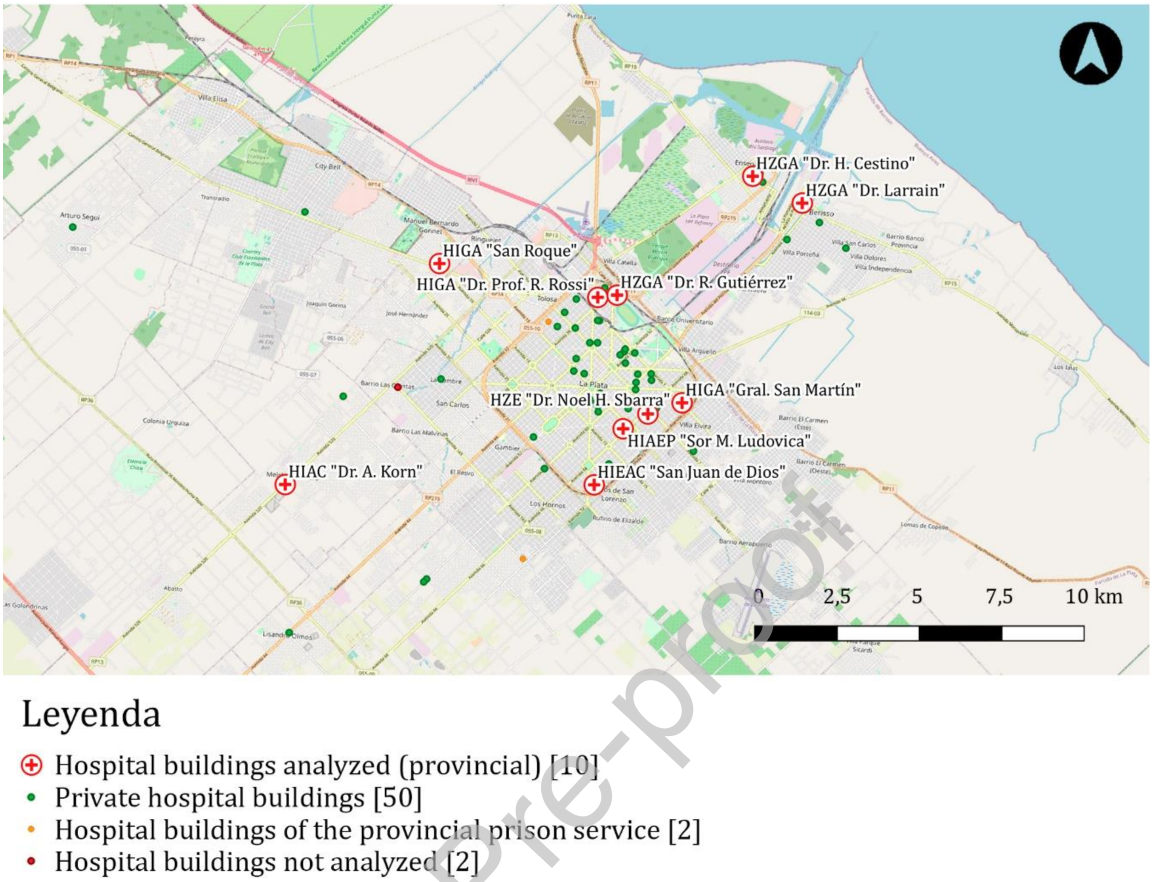


Fig. 2. Georeferencing of MRGLP's hospitals under different dependencies

Table 1. Characterization of MRGLP public hospitals by productive health, morphological, and territorial variables

Hospital buildings	**Numbers of beds available**	**Exposed surface [m²]**	**Built-up area [m²]**	**Number of floors**	**Population density [Pop/ha]**	**Occupancy factor**
HZGA "Horacio Cestino"	41	4,426.84	3,764.58	n/d	800	0.68
HZE "Dr. Noel H. Sbarra"	83	5,124.09	4,687.88	3	400	0.44
HZGA "Dr. Larrain"	78	6,831.68	5,301.13	n/d	400	0.70
HZGA "Dr. Ricardo Gutiérrez"	95	9,435.77	6,776.88	3	400	0.40
HIGA "Dr. Prof. Rodolfo Rossi"	104	9,593.10	11,863.33	3	400	0.75
HIEAC "San Juan de Dios"	110	27,358.68	20,864.85	3	400	0.25
HIGA "San Roque"	148	11,251.09	11,126.51	n/d	n/d	0.36
HIAEP "Sor María Ludovica"	264	30,679.51	30,123.50	8	1,800	0.71
HIGA "Gral. San Martín"	324	54,085.63	39,225.62	6	1,800	0.73
HIAC "Dr. Alejandro Korn"	644	70,799.97	42,943.41	n/d	n/d	0.06

Table 2. Characterization of MRGLP public hospitals by energy performance variables

Hospitals	Electric consumption [TOE/year]	Natural gas consumption [TOE/year]	Total consumption [TOE/year]	Total solar radiation [TOE/year]
HZGA "Horacio Cestino"	35.18	37.22	72.40	404.60
HZE "Dr. Noel H. Sbarra"	24.38	17.92	42.30	450.06
HZGA "Dr. Larrain"	43.05	60.42	103.47	575.72
HZGA "Dr. Ricardo Gutiérrez"	41.69	61.02	102.71	905.67
HIGA "Dr. Prof. Rodolfo Rossi"	99.90	154.19	254.09	784.81
HIEAC "San Juan de Dios"	88.73	96.10	184.83	2,376.78
HIGA "San Roque"	101.28	135.30	236.58	1,086.07
HIAEP "Sor María Ludovica"	347.15	255.85	603.00	1,947.81
HIGA "Gral. San Martín"	373.82	493.22	867.04	3,736.28
HIAC "Dr. Alejandro Korn"	143.39	719.35	862.74	6,966.46

3.2. HIEAC "San Juan de Dios"

To exemplify the application of stage 2, the "San Juan de Dios" Specialised Interzonal Hospital for Acute and Chronic (HIEAC) has been chosen, which has an annual consumption of 88.73 TOE in electricity and 96.10 TOE in natural gas. Fig. 3 shows that in the winter period there is a notable increase in the natural gas consumption, with the highest values for this source in July (29.29 TOE). Meanwhile, electricity consumption presents higher values for the month of February (9.15 TOE).

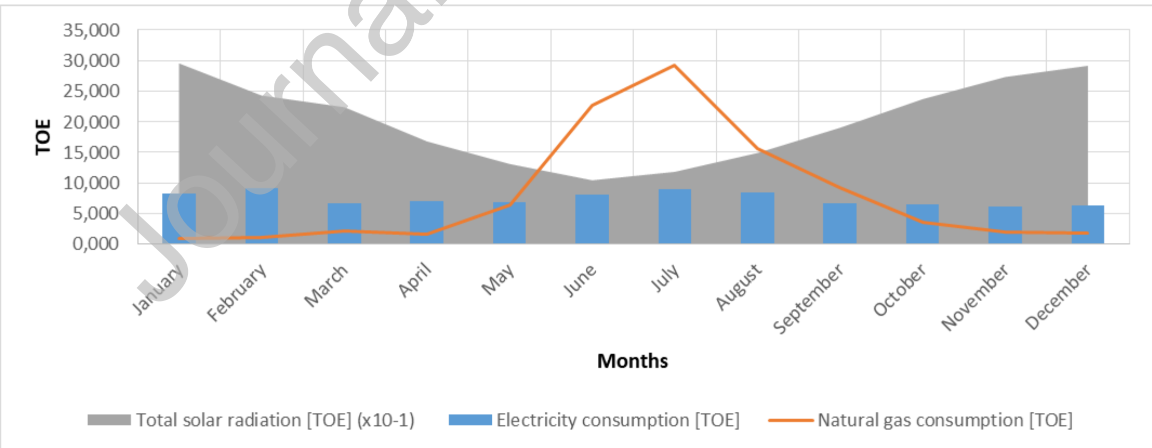


Fig. 3. Annual consumption of HIEAC "San Juan de Dios".

3.3. Instituto del Tórax pavilion

To better illustrate the stage 3, the study was carried out working on the Instituto del Tórax (Fig. 4), a pavilion dedicated to the care of thoracic-cardiovascular and pulmonary pathology and infectious diseases.

Fig. 4. Location of the Instituto del Tórax pavilion in HIEAC "San Juan de Dios"

4. Results

4.1. Ranking of potential hospitals – MRGLP provincial hospital network

The results obtained from the application of the proposed solar indexes are shown in Table 3. The ranking of potential hospitals according to II and the ranking of potential hospitals according to SI can then be seen in Fig. 5 and Fig 6, respectively. In this case, the Interzonal Acute and Chronic Hospital (HIAC) "Dr. Alejandro Korn" as a viable alternative both for injecting electricity into the grid and for harnessing solar radiation, regardless of what is to be done with it. While the HIEAC "San Juan de Dios" is presented as the most viable alternative for the substitution of non-renewables sources with renewable ones.

Table 3. Hospital buildings with solar index (ranked by solar gain index)

Hospital buildings	**Solar gain index**	**Substitution index**	**Injection index**
HIAC "Dr. Alejandro Korn"	0,69	8,07	48,58
HIGA "San Roque"	0,67	4,59	10,72
HZGA "Dr. Ricardo Gutiérrez"	0,67	8,82	21,73
HZGA "Horacio Cestino"	0,64	5,59	11,50
HIEAC "San Juan de Dios"	0,62	12,86	26,79
HZE "Dr. Noel H. Sbarra"	0,61	10,64	18,46
HZGA "Dr. Larrain"	0,59	5,56	13,37
HIGA "Dr. Prof. Rodolfo Rossi"	0,57	3,09	7,86

HIGA "Gral. San Martín"	0,48	4,31	9,99
HIAEP "Sor María Ludovica"	0,44	3,23	5,61

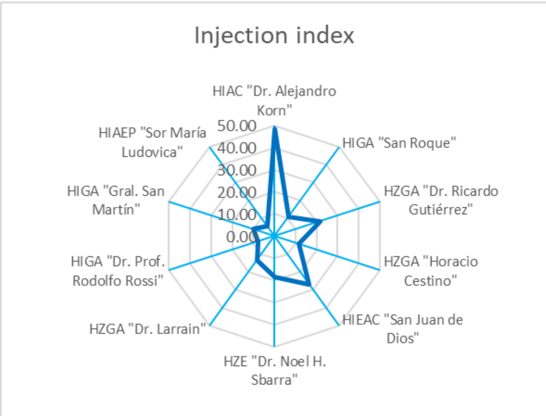


Fig. 5. Potential hospitals according injection index

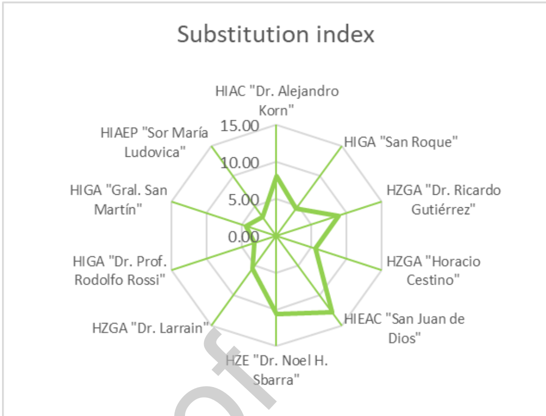


Fig. 6. Potential hospitals according substitution index

4.2. Detection of suitable sectors – HIEAC "San Juan de Dios"

From the analysis of the consumption in the hospital, a relatively homogeneous consumption of electricity and a more heterogeneous consumption of natural gas were observed. Electricity consumption showed a smaller dispersion compared to natural gas consumption ($r_{electricity}$= 14% vs. $r_{natural\ gas}$ = 119%). Thus, using HD-SARSE, an annual simulation was carried out for the detection of suitable sectors to locate PVS, and the tool was used for the month of July for the detection of sectors for the installation of STS.

Fig. 7 shows that the roofs of the Instituto del Tórax pavilion are suitable for the incorporation of PVS, while the north-facing façade presents the appropriate situation for the installation of STS. From an analytical point of view (Fig. 8), 801 points were examined on the different surfaces of the surfaces (roofs, and North, South, East, and West façades). From the annual simulation, higher solar irradiance values were obtained on the roofs: 312 points were analyzed, which presented maximum values of 1,641.67 kWh/m^2, minimum values of 205.45 kWh/m^2 and an average of 1,265.86 kWh/m^2. In the case of the July simulation, the highest solar irradiance values were found on the North façade: 213 points were analyzed, with maximum values of 94.36 kWh/m^2, minimum values of 24.34 kWh/m^2 and an average of 92.96 kWh/m^2.

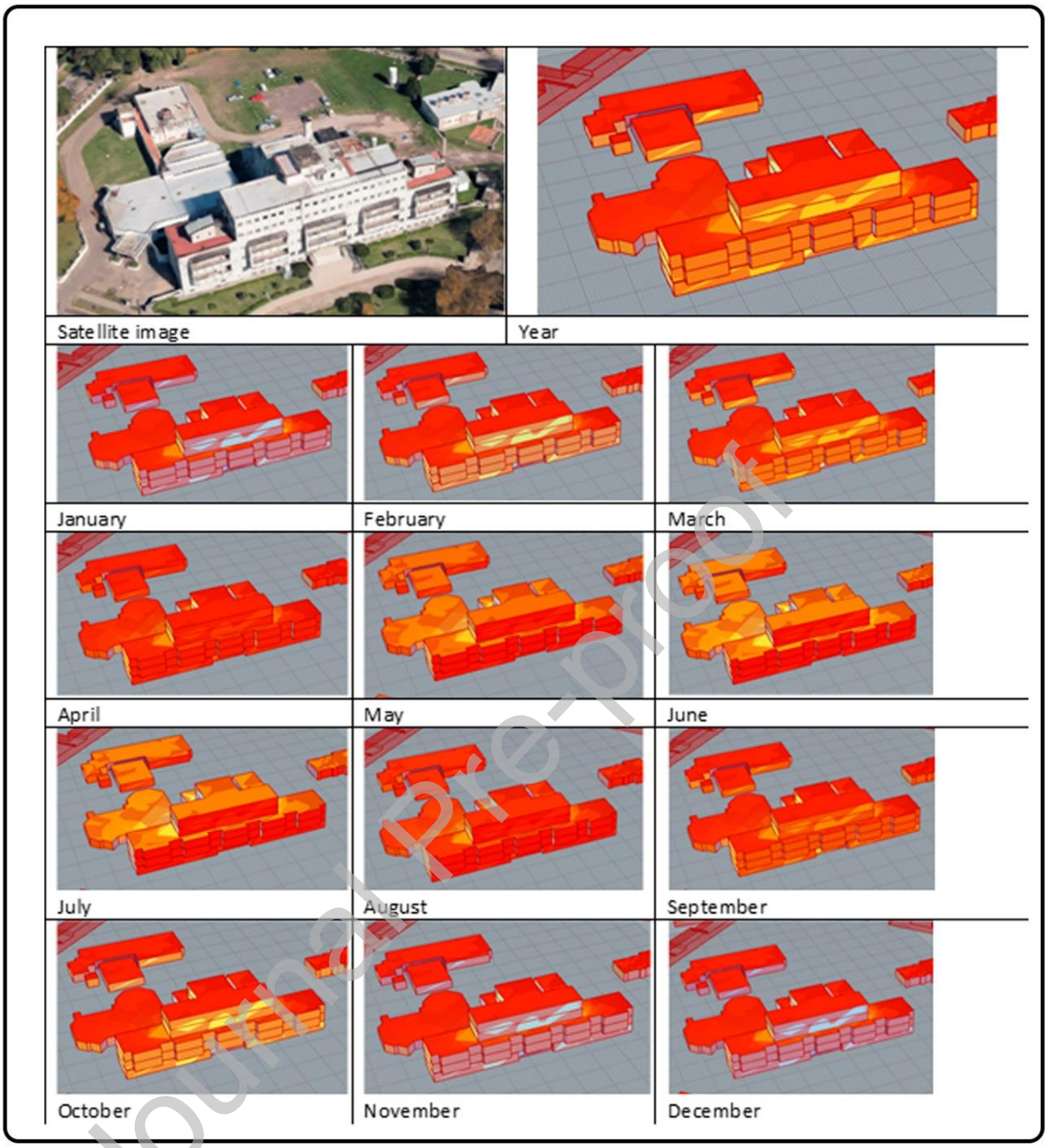


Fig. 7. Graphical results of the Instituto del Tórax pavilion from monthly and annual analysis on HD-SARSE

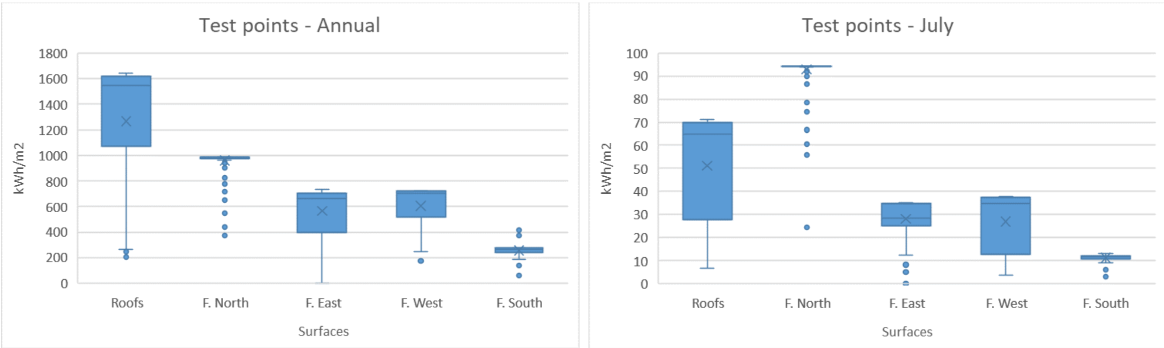


Fig. 8. Analytical results of Instituto del Tórax pavilion from July and annual analysis on HD-SARSE

4.3. SSEU feasibility study - Instituto del Tórax pavilion

Considering that natural gas consumption is more critical than electricity consumption in the hospital under analysed, this study focuses on the application of strategies to substitute heat energy. Likewise, the incorporation of systems in the North façade of the building is proposed. In this way, the "Coronary Unit" hospitalization service (Fig. 9) is assisted by preheating the water for heating in the winter period and on certain days of the equinoxes (185 days) and supplying DHW to the entire building on days when the heating system is not used (180 days). This sector has an area of 647 m^2 and an average height of 2.7 m.

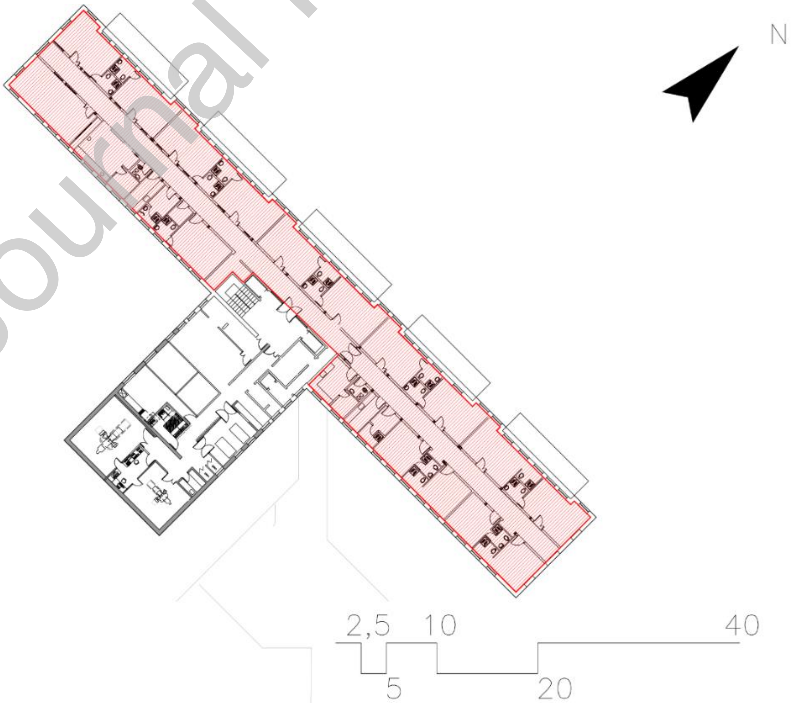
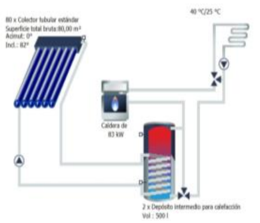
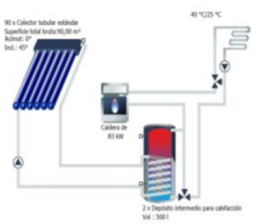
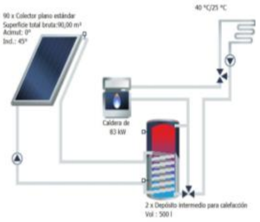
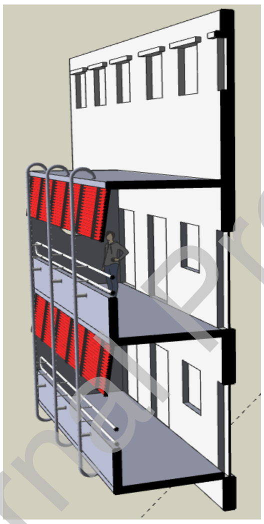
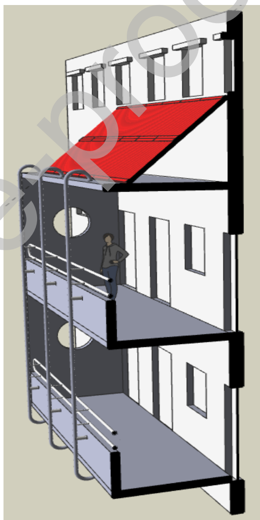
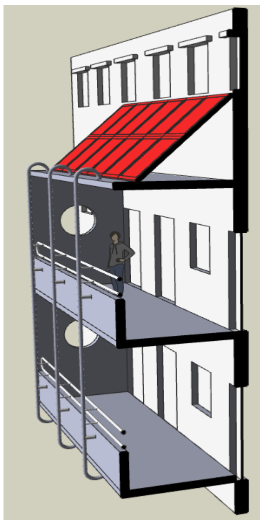


Fig. 9. Coronary care unit service

Fig. 10. North façade of Instituto del Tórax pavilion

To apply stage 3, the technical-constructive resource is the protruding modules of the rooms oriented to the North (Fig. 10). The results of 3 SSEU for natural gas replacement (STS_1, STS_2 and STS_3) are examined on these existing elements, placing the collector field as a "sunshade" or on the upper slab, in a space inaccessible to the patient. Table 4 summarises the characteristics of the components of each strategy.

Table 4. Characteristics of proposed strategies

Strategy	**STS_1**	**STS_2**	**STS_3**
Type of system			
Installed power [kWp]	52.18	58.7	49.25
Numbers of panels	80	90	90
Technology	Evacuated tube	Evacuated tube	Flat plate
Orientation	North	North	North
Tilt [°]	81.99	44.7	44.7
Incorporation into the building element			

4.3.1. Architectural integration

In terms of integration with the existing design of the building, strategy STS_1 is partially coherent considering geometry, modulation, and materiality. Strategies STS_2 and STS_3 are partially coherent in the geometry of the building and do not maintain any coherence with the materiality and the modular pattern (Table 5).

Table 5. Integration with architectural design

Coherence	Strategy					
	STS_1		STS_2		STS_3	
Geometry	Partial	●	Partial	●	Partial	●
Materiality	Partial	●	No coherence	●	No coherence	●
Modulation pattern	Partial	●	No coherence	●	No coherence	●

4.3.2. Fossil fuels and GHG emissions savings

The energy-environmental impact of strategy STS_1 presents an annual saving of 3,714.87 m^3 of natural gas and avoids the emission of 7,853.71 kg of CO_2 per year; using strategy STS_2 would result in a saving of 4,677.22 m^3 of natural gas and avoids the emission of 9,888.79 kg of CO_2. finally, using strategy STS_3 would result in an annual saving of 4,063.14 m^3 of natural gas per year and avoids the emission of 8,590.24 kg of CO_2. Table 7 shows the values obtained for each strategy, distinguishing between the results for heating and DHW.

4.3.3. Economic performance

Applying NPV, with energy subsidy, none of the strategies manages to maintain a PBT lower than the useful life of the system. If the same subsidy (70%) is transferred to the strategies to be implemented, they are no longer viable after a certain interest rate. In the case of strategy STS_1, the project is not viable at an interest rate above 7%. While for strategies STS_2 and STS_3, the projects will be unviable from an interest rate above 10% (Table 6).

Table 6. Economic analysis (with strategy subsidy)

Subsidy	SSEU					
Final price of energy [USD/m^3]	0.299					
Final price of technologies [USD/kWp]	214.5					
Strategy	STS_1		STS_2		STS_3	
k	NPV	PBT [years]	NPV	PBT [years]	NPV	PBT [years]
0.00	14,941	11	21,961	9	17,010	10
0.01	11,830	11	17,846	10	13,726	10
0.02	9,216	12	14,392	10	10,969	11
0.03	7,010	13	11,475	11	8,642	11
0.04	5,138	14	9,000	12	6,666	12
0.05	3,541	16	6,888	12	4,981	13
0.06	2,171	18	5,076	14	3,535	15
0.07	990	20	3,515	15	2,289	16
0.08	-34	>25	2,162	17	1,210	19
0.09	-924		984	20	270	23
0.10	-1,704		-46	>25	-553	>25
0.11	-2,389		-952		-824	

Table 7. Contributions of each strategy

Strategy	**Uses**	**Period**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
STS_1	Heating	Natural gas savings [m^3]	0	0	0	0	235	385	415	350	306	69	0	0	1,759
		CO_2 emissions avoided [kg]	0	0	0	0	496	814	877	740	647	146	0	0	3,719
		Fraction solar [%]	0	0	0	0	18	14	12	16	22	19	0	0	16
		Heating (solar energy) [kWh]	0	0	0	0	2,079	3,408	3,670	3,097	2,708	611	0	0	15,575
		Heating (aux. system) [kWh]	0	0	0	0	9,239	21,238	25,868	16,578	9,434	2,532	0	0	84,889
	DHW	Natural gas savings [m^3]	576	440	279	180	0	0	0	0	0	0	489	620	2,583
		CO_2 emissions avoided [kg]	1,217	930	590	380	0	0	0	0	0	0	1,033	1,311	5,461
		Fraction solar [%]	86	73	41	27	0	0	0	0	0	0	78	92	66
STS_2	Heating	Natural gas savings [m^3]	0	0	0	0	278	454	508	451	419	106	0	0	2,218
		CO_2 emissions avoided [kg]	0	0	0	0	589	960	1075	954	886	225	0	0	4,690
		Fraction solar [%]	0	0	0	0	22	16	15	20	31	30	0	0	20
		Heating (solar energy) [kWh]	0	0	0	0	2,466	4,022	4,503	3,997	3,711	942	0	0	19,642
		Heating	0	0	0	0	8,85	20,62	25,03	15,67	8,43	2,20	0	0	80,82

		(aux. system) [kWh]					3	4	3	6	0	4			0
	DHW	Natural gas savings [m^3]	724	553	351	226	0	0	0	0	0	0	615	779	3,248
		CO_2 emissions avoided [kg]	1,530	1,169	742	478	0	0	0	0	0	0	1,299	1,648	6,866
		Fraction solar [%]	100	91	52	35	0	0	0	0	0	0	98	100	83
STS_3	Heating	Natural gas savings [m^3]	0	0	0	0	221	348	379	340	325	82	0	0	1,695
		CO_2 emissions avoided [kg]	0	0	0	0	467	735	802	720	686	174	0	0	3,584
		Fraction solar [%]	0	0	0	0	17	12	11	15	24	23	0	0	15
		Heating (solar energy) [kWh]	0	0	0	0	1,958	3,079	3,358	3,014	2,874	726	0	0	15,009
		Heating (aux. system) [kWh]	0	0	0	0	9,359	21,569	26,200	16,665	9,269	2,417	0	0	85,478
	DHW	Natural gas savings [m^3]	668	511	264	170	0	0	0	0	0	0	507	719	2,839
		CO_2 emissions avoided [kg]	1,412	1,079	559	360	0	0	0	0	0	0	1,072	1,521	6,003
		Fraction solar [%]	100	84	39	26	0	0	0	0	0	0	81	100	73

5. Discussion

Based on a workflow that allows intervention at different scales, a diagnostic tool is provided to detect potential for SSEU implementation in the health sector. Thus, it was applied in a provincial hospital network corresponding to the MRGLP (Argentina), following 3 stages: i. Ranking of potential hospitals; ii. Detection of suitable sectors; and iii. SSEU feasibility studies.

5.1. Ranking of potential hospitals – MRGLP provincial hospital network

In the first stage, it can be observed that the territorial variables that define the urban area of the hospital (population density and number of floors) maintain a good correlation with the SGI value (Fig. 11). Although hospitals with a "block" morphology have a higher potential for solar energy utilization [52], it is shown that the environment has a greater influence on the determination of this factor. Hospitals with a "pavilion" morphology located in peripheral areas of the city have a high profile for the incorporation of SSEU, while the "block" morphology, such as the HIGA "Dr. Rodolfo Rossi", located in urban center, has lower solar index values. The peripheral areas in the MRGLP do not specify permitted building levels, as they are wet or productive areas, which presents a positive situation in terms of a lower level of obstructions or shadows generated by nearby buildings. This observation is also associated with population density, i.e., the number of inhabitants permitted for each urban area: the lower the permitted population density, the further away it is from the urban context.

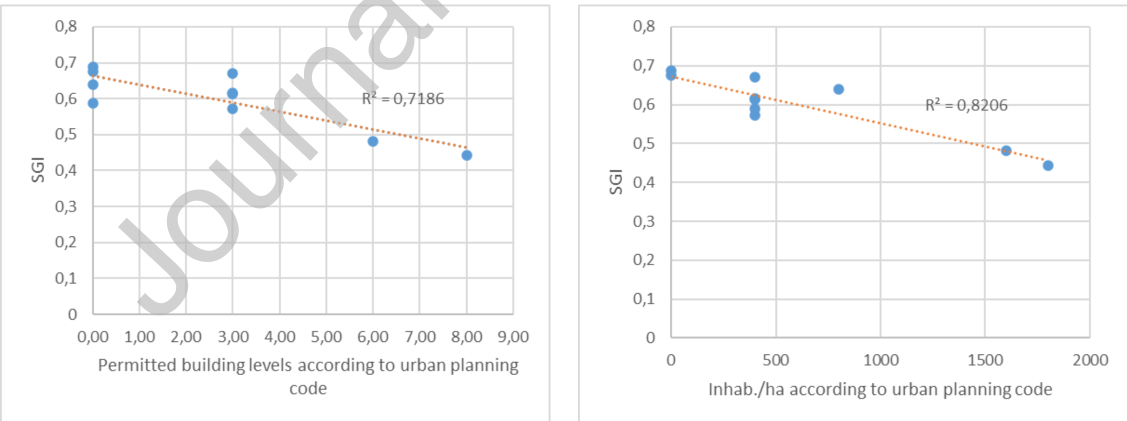


Fig. 11. Correlation between SGI and hospitals by territorial variables

In terms of RI, the HIEAC "San Juan de Dios" maintains a low TR_{ext} compared to other buildings. However, by consuming less energy from conventional sources, it has a higher potential for substitution of heat and electrical energy. In the case of potential hospitals according to II, the HIAC "Dr. Alejandro Korn" maintains a high value compared to the other hospitals due to its high dependence on natural gas consumption (83% of the total energy consumed). Thus, by maintaining a high TR_{ext} and a relatively low consumption of electricity, it allows it to adopt a potential profile for the injection of electricity into the public grid through the incorporation of PVS.

5.2. Detection of suitable sectors – HIEAC “San Juan de Dios”

The simulation using HD-SARSE showed the ideal sectors for one of the pavilions of the HIEAC "San Juan de Dios". Logically, the highest values of the annual simulation were perceived in the roofs, however, detailed geometries were not modelled in this study, omitting elements that generate shadows and limit the number of panels to be installed. In this case, no water tanks, vents, or external HVAC units were modelled. As for the values obtained on the building façades, different solar irradiance points are conceived for each orientation. Nevertheless, it is valid as a methodological step, as the following step will analyze the possible arrangements and types of technologies in detail. The North façade maintained higher values than the rest of the surfaces for the month of July, which is attributed to the few obstructions in this orientation and to the break in the grid that makes up the city (NE, SE, SW and NW) (Fig. 4).

Subsequently, the incorporation of STS with collectors inclined at 44.7° was analyzed. This may call into question the process of assigning SSEU according to the solar radiation values on surfaces whose inclination is different (0° for roofs and 90° for façades). However, there are different SSEU that copy the inclination of the surfaces where they are installed for aesthetic reasons (PVS simulating fenestration, for example) or because of the nature of the system itself (heat storage wall [53], trombe wall [54], solar hot air collectors [55], among others). It is for this reason that integration into the architectural design has been incorporated as an evaluation variable. Likewise, for this factor to acquire greater importance in the evaluation process, it is necessary to have more options when comparing strategies.

5.3. SSEU feasibility study - "Instituto del Tórax" pavilion

Analysing strategy STS_1, it is noticed that it maintains greater coherence with the existing architectural design, due to a stronger relationship with the modulation pattern and materiality. However, it is observed that incorporating the solar collectors in the form of a "sunshade" (Table 4) means reducing hours of natural light in the winter period, in addition to providing difficulties when performing maintenance tasks. On the other hand, the STS_2 strategy offers better results in terms of fossil fuels and GHG emissions savings and economic results, due to the orientation, greater quantity, and type of collectors. This is mainly due to the sector selected to incorporate STS. By using the inaccessible roof, greater number of solar collectors (90) can be installed with an inclination of 44.7°, whereas as a "sunshade", fewer collectors (80) can be installed with an inclination of 82°. Finally, the STS_3 strategy presents values ranging between the worst and intermediate positions in the 3 dimensions of analysis. Although the number, location and orientation of panels is the same as that used in STS_2, what changes in this case is the technology in the collector field, using in this case flat plate collectors. Although this type of collector has a higher efficiency in summer, the tubular type has a higher performance in winter and at the equinoxes [56].

It should be noted that for these strategies to be viable, at least from an economic point of view, policies that promote renewable energies for distributed generation must be developed. If the economic analysis had not been carried out assuming a 70% subsidy on the cost of the systems and not on the energy, the NPV would be negative and the PBT would exceed the useful life of any of the strategies analysed. In this sense, some of the barriers that prevent the promotion of solar energy systems are the low price of natural gas in Argentina compared to other countries [57,58], the lack of economic incentives for the insertion of renewables, mistrust towards new technologies and concern about intermittent production [14]. Also, in almost all countries, the total cost of fuel includes exploration, production, distribution and use, but does not include the damage it causes to the environment and society, so these impacts must be considered to assess the real cost of using fuels from fossil sources for energy generation [21].

Analysing the three strategies, the economic results show a payback of the investment within 9 years in the best case and, when the imposed rate is close to 9%, it exceeds 19 years. This can be explained by the decision to use strategies to substitute energy for space heating in the winter period and on certain days of the equinoxes. The calculations showed a solar fraction for heating of 16%, 20% and 15%, corresponding to strategies STS_1, STS_2 and STS_3, respectively. Thus, it is observed that it is difficult to substitute natural gas in space heating, considering that these do not maintain an adequate thermal insulation [59–61]. At the same time, covering the heating demand for a volume of 1,746.9 m^3, with the requirements of the hospitalisation area, is insufficient with STS with a peak power of 60 kWp. In terms of DHW supply, the strategies maintain good coverage when the STS no longer contributes to heating (270 days (summer and equinoxes)). Thus, the STS_2 strategy offers a solar fraction of 83%, followed by the STS_3 strategy, with 73% and 66% belonging to the STS_1. Being a particularity the proposal of a mixed system, it is difficult to compare results with other facilities with STS, since in [18], for example, a coverage of 35% of DHW consumption is obtained, but through a system designed to collaborate with this use 365 days a year.

Based on the above, it is established that STS_2 strategy is the most viable strategy for the case study. Although it is not integrated into the architectural design as strategy STS_1 is, it can be observed that it is superior in both the energy-environmental and economic dimensions.

6. Conclusion

The implementation of SSEU in hospital buildings can make a significant contribution to reducing fossil fuel consumption and saving GHG emissions, as well as moving towards a scenario of independence from these sources. However, there are currently barriers to their deployment, especially in developing countries. The literature review showed that diagnostic and optimization tools have been developed for the use of solar energy at different city scales, providing new information to decision-makers. In this way, the development of sustainable policies for the application of solar systems is facilitated, although the modes and processes carried out in the works analyzed do not apply to the health sector. Hospitals, as they have particular energy behavior profiles and operate on the basis of the grid concept, should be analyzed separately from other building typologies.

In this sense, the objective of this work was to provide a model for the implementation of SSEU in the health sector. To this end, a workflow was developed that allowed intervention at 3 levels of analysis (health network, hospital, and pavilion), where it was proposed to: i. Identify hospitals with solar potential in a health network; ii. Sectorize suitable surfaces in potential hospitals for the implementation of SSEU; and iii. Determine the architectural, environmental, and economic feasibility of solar technologies. In this way, a diagnostic tool was elaborated that takes into account the particularities of buildings in the health sector.

From the construction of solar indexes based on a purpose (injecting electricity into the grid or replacing fossil fuels), information is provided to direct resources according to the priority or condition of each hospital. Likewise, the relationship between territorial and energy variables allowed detecting that hospitals located in peripheral areas present a higher value according to the solar gain index than those located in urban contexts.

When installing systems, linking the critical consumption of a fuel to the surface solar radiation values provides a criterion based on the priorities of the hospital considering the possibility of hosting STS and PVS at the same time. The influence of the orientation and morphology of the hospital in defining the location and number of solar systems was also demonstrated, which assists in design guidelines for future constructions.

Finally, different systems were analysed in terms of architecture, fossil fuel savings and GHG emissions and economics. Although the most feasible was established in relation to these factors, in Argentina, under current policies no project is economically viable. For this reason, an alternative scenario was created where energy subsidies are shifted to access to solar systems. This step constitutes a quantitative argument for the management authorities, so that programmes can be designed to incentivise the application of SSEU in the health sector.

On the other hand, as a next study it is considered necessary to develop a much broader catalogue of strategies, so that architectural integration gives more weight to the evaluation of strategies. Thus, once the technology has been selected, the workflow set out in the model could be extended to maintain optimisation in the operation of subsystems through management [62] or monitoring techniques using IoT [63,64]. In order to do so, a descent to the level of analysis of the hospital area or building module must be carried out, where the behaviour of the subsystems of the strategy to be used will be analysed in detail.

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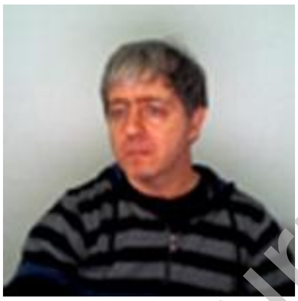

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Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: