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Methodology developed for the energy-productive diagnosis and evaluation in health buildings

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Abstract

The public health network in Argentina consists of a wide variety of buildings presenting a complex system of services and structures. In order to modulate and study the energy behaviour of each type of health facility, a database of *Energy-Productive Building Modules* (Módulos Edilicios Energéticos Productivos: MEEP) was built. This involved evaluating the interactions among physical spaces, building envelope, infrastructure, and equipment usage with the energy consumption, for each specialty service provided in the most common buildings present in the health service network.

The MEEP database enables investigators to:

(i) Obtain detailed information on each facility.
(ii) Identify variables critical to an energy consumption perspective.
(iii) Detect areas of over consumption and/or inadequate infrastructure.
(iv) Gather essential reference material for the design of health facilities and other similar sectors.

The information of each MEEP can be summarized in typological charts.

Keywords: Energy productive building audit; Optimization; Habitability

1. Introduction

The Argentine public health building network consists of a wide diversity of high and medium complexity buildings characterized by energy intensive infrastructure and equipment.

Such a system presents various problems, particularly of hygrothermal habitability and non-conscious use of energy, which have a great impact on the quality of services provided. During the 1990s, the restructurization of the government led to the privatization and decentralization of basic public services, including energy providers. Health care buildings had to restrict energy use due to potential supply disruptions. The inadequate supply and risk of power failure necessitated an evaluation of energy consumption in this sector.

Poor administration, inadequate management and regulation of services, and inequitable resources distribution led the country into a deep socio-economic crisis, resulting in a 22% unemployment rate. The employment situation affected all levels of the health services sector (private companies, medical insurance systems, etc.) resulting in a trend for private clients to move into the public system. This unforeseen increase in users created an imbalance leading to the collapse of the budget. The situation culminated in a drastic decrease in energy consumption, which greatly compromised service quality. At the same time, medical services and technological advances led to a greater demand for energy [1], further enlarging in some cases the gap between needs and available resources.

In Argentina there are approximately 3200 public health care buildings, making up about 75,000 beds. Private institutions number around 1500, representing approximately 67,000 beds. In Buenos Aires, the country's most populated province, a high-complexity health market exists concentrated

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Nomenclature

A	area (m^2)
A_t	glass specific thermal transmittance (m^2)
A_o	wall specific thermal transmittance (m^2)
$°D$	heating degree days (K)
DG	direct gain through window
E	luminance (lx)
$E_{\%}$	luminance (lx) according to the percentage established by the RAFIS programme in relation to the external natural lighting
EF	exposition factor
GP	gain per person (W)
h	room's height (m)
J_a	air enthalpy (kJ/kg K)
K	thermal transmittance (W/m^2 K)
K_o	thermal transmittance for opaque envelope (W/m^2 K)
K_t	thermal transmittance for glass envelope (W/m^2 K)
n	ventilation rate (vol/h)
n_d	number of days
n_e	number of equipments
n_p	number of people
OF	occupation factor
P	electricity power (kW)
TOE	tonnes of oil equivalent (1 TOE = 11,600 kWh)

Greek letters

η	luminous efficiency (lm/W)
η_C	caloric efficiency
ρ_a	air density (kg/m^3)
τ	time (h/day)

in the metropolitan area. The national average building distribution between publicly and privately administered health care buildings is approximately 25–30, and 75 and 70%, respectively [1]. In spite of attempts to improve the health care in Argentina, we still do not have a regulatory system related to the rational use and conservation of energy in this sector. The methodology developed in this paper proposes alternatives, methodologies and tools to identify and measure variables with the aim of improving energy efficiency.

2. Methodology

The analysis of energy needs for health facilities defined as nodes of a network was implemented at a global and detailed level. At the global scale, the basic units of analysis used were the nodes or buildings of the network, and on the detailed level, the basic units of analysis used were the energy-productive building modules (Módulos Edilicios Energéticos Productivos: MEEP) or ''building differentials''

The Argentine health network represents a complexity and a morphological diversity of old and new buildings. To identify the energy consumption of each area within the different health facilities, a detailed methodology was developed that enabled the relation of energy variables of each health speciality through a differential analysis construction. This methodology involves analysing the buildings from a construction typology catalogue, which modulates the representative units of various hospitals.

This analysis formed the basis of the MEEP database. The database allows us to classify, describe, compare and design different health facilities using representative typology units that characterize the buildings and energetic and productive needs of each health facility unit (laboratory, surgery, intensive care, etc.).

The methodology developed at a detailed level was based on the analysis of the different energy demands of each health facility. These MEEPs (differentials) are characterized by their specific functions, significant energy requirements, and diversity of demand related to temperature needs and type of equipment of each unit.

The construction of each MEEP was carried out by calculating the following variables:

(i) Lighting consumption: general lighting of the module and local lighting on the working plane.
(ii) Equipment consumption: quantity, use and average energy consumption of each equipment.
(iii) Comfort conditioning consumption: energy contributions and losses on a simplified energy balance. Here the analysis variables are: occupation, lighting, equipment, direct gain through windows (DG), ventilation rate and envelope characteristics. The energy needs arise from this balance.

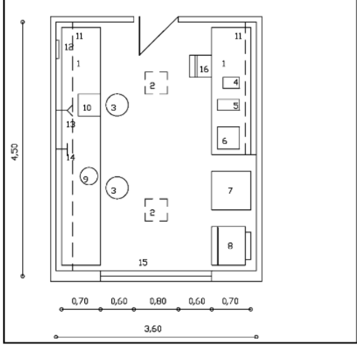
Each MEEP is summarized in a typological chart with information related to (Fig. 1):

(i) MEEP identification and involved area.
(ii) Layout.
(iii) General characteristics: localization, dimensions, envelope characteristics, mean interior and exterior temperature and orientation.
(iv) Lighting system characteristics and energy consumption calculation values.
(v) Equipment characteristics and consumption calculation values.
(vi) Consumption calculation values for comfort conditioning (contributions and losses by occupation, direct gain through window, lighting, equipment, ventilation rate, and envelope).
(vii) Partial consumption values (of each variable) and total consumption values (of the whole MEEP).

Construction of the database involved systematization and analysis of four complementary instances for each MEEP. These are: Theoretical MEEP, Real MEEP, Optimized MEEP and Environmental MEEP.

1. *Theoretical MEEP*: the development of the theoretical catalogue describes the physical space, envelope, infrastruc-

Denomination: LABORATORY **Area:** Diagnostic and Treatment	**THEORETICAL**	**MEEP DT1a**

PLAN	**REFERENCES**	**GENERAL DATA**
	1 - Table 2 - General lighting 3 – Chair. Adjustable height 4 - Microscope 5 - Analytic scale 6 - Sterilization cultivation stove 7 - Centrifugal 8 - Cooler 9 - Basin 10 – Acid resistant basin 11 - Bookcase 12 - Clock 13 - Pick of gas 14 - Aspiration pick 15 - Window 1m x 2m 16 - Chair 17 - Lighting on the working plane	Constructive System.: Traditional Orientation: E-O Area: 15.75 m² Exterior opaque area: 10.60 m² Exterior glass area: 2 m² Height: 3.50 m Inside T°.: 25°K °D: 994 Mean exterior T°: 17.5°K

LIGHTING			
General (fluorescent)	500 lux	12 hr	
Local (incandescent)	800 lux	8 hr	2 m²
TOTAL kWh/day.m²			**0.49**

EQUIPMENT		
Sterilization stove	1000 W	10 hr
Cultivation stove	1000 W	24 hr
Thermostatic bath for 90 tubes	1000 W	5 hr
Cooler	50 W	24 hr
Microdiluctor	1150 W	4 hr
Vortex	110 W	2 hr
Centrifugal of table	200 W	5 hr
Analyzer of PH	20 W	5 hr
Flame photometer	200 W	3 hr
Extraction Chamber	370 W	4 hr
Spectrophotometer UV	50 W	5 hr
Portable stove	5250 W	4 hr
Other equipment		
TOTAL kWh/day.m²		**4.549**

COMFORT CONDITIONING					
Occupation	DG	Ventilation rate	Envelope	Lighting	TOTAL
N°.: 4 people Hr.: 12 O.F.: 0.6	Exposed Window Simple glass	N°.: 8 vol. / hr Air. Density: 1.3 kg/m³ Enthalpy: 0.99kj/kg°K	K.op. area: 2.21 kW/m²°K K.trans. area: 5.8 kW/m²°K	**0.082** Equipment	kWh/day.m²
0.183	**0.123**	**1.441**	**0.321**	**4.549**	**3.174**

	Theoretical		Polluting Emission kg/m² year					
	kWh/day.m²	TOE/year.m²	PM10	SO_2	NO_x	HC	CO	CO_2
Lighting	0.149	0.019	0.007	0.190	0.051	0.004	0.014	57.95
Equipment	4.549	0.572	0.217	5.720	1.544	0.109	0.440	1744.0
Comfort Conditioning	3.174	0.099	0.019	-	0.178	0.038	0.048	270.27
MEEPA	**7.872**	**0.690**	**0.243**	**5.910**	**1.773**	**0.151**	**0.502**	**2072.2**

Fig. 1. Typological chart.

ture, equipment, energy consumption and minimum needs use. This allows investigators to diagnose theoretical energy load and pollutant emissions; to establish potential energy saving locations; to minimize pollution; to facilitate new expansions or building design; to determine standard values in the envelopes; and to promote the availability of physical spaces in a systematic and economically equitable manner.

2. *Real MEEP*: this arises from the reformulation of the theoretical MEEP according to the existing building and services network. This allows investigators to verify distortion between the Theoretical MEEP and the existing health network reality, and to detect distortions of excess or defect, enabling the re-evaluation of variables.
3. *Optimized MEEP*: analysis of the Theoretical + Real MEEP will provide basic information proposing energy-productive building improvements for each health differential, representing the optimum needs for each unit of a particular hospital.
4. *Environmental MEEP*: this is calculated by pollutant emissions considered as a function of the energy flows involved in each module. Energy contributions and losses are analyzed, and their respective emissions are evaluated. Obtained values are specific for each module and for each pollutant.

In order to adjust the way the modules operate, an integrated methodology was developed to facilitate analysis of the different levels of service in each hospital. Fig. 2 shows an example of the integration levels in a hospital belonging to the Argentine public health network.

The Argentine public health network consists of nodes (hospitals) of different complexity. Each building (hospital) is

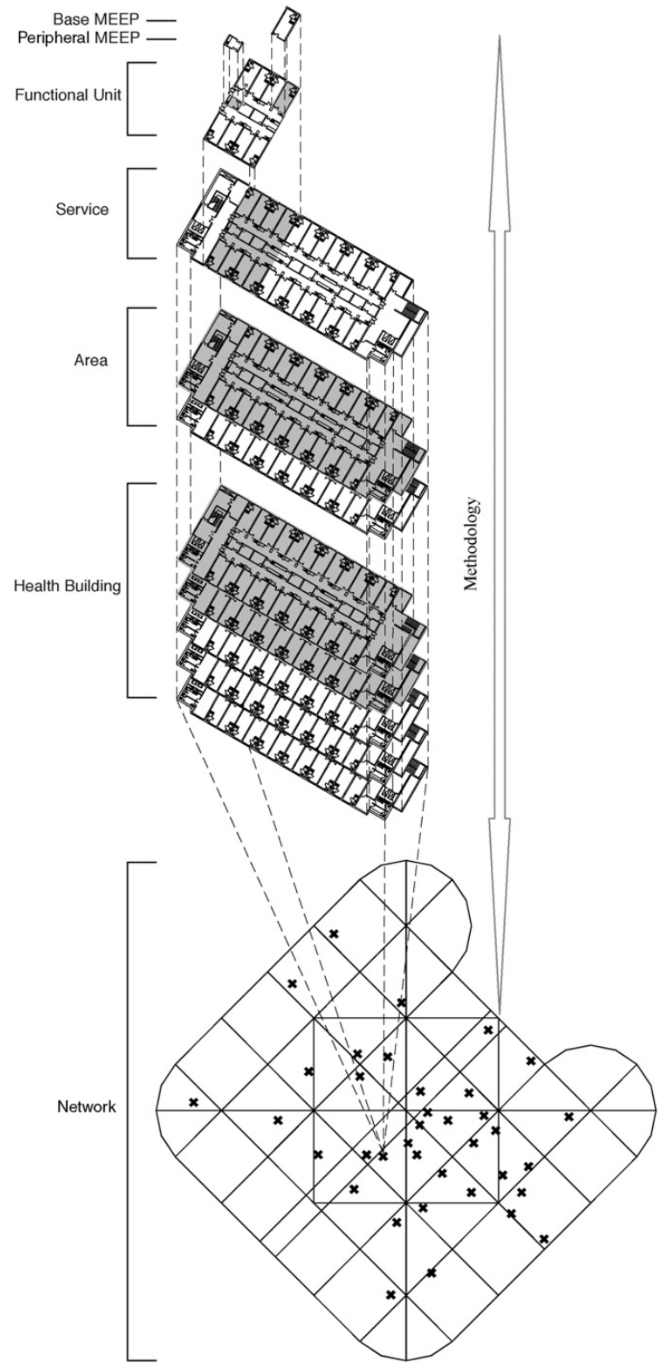


Fig. 2. Integration levels.

composed of a group of *Areas*. These areas contain groups of *Services*, integrated by *Functional Units*. The Functional Units involve *basic MEEP* and *peripheral MEEP*. The basic MEEP represent the differential, and the peripheral MEEP are interrelated to the basic MEEP. These peripheral MEEP do not reach the differential service category although they do contribute to functions of the process and, in some cases, are significant in relation to energy consumption.

For example, the MEEP ‘‘Two beds room’’ forms the ‘‘Intern Functional Unit’’ that is represented by a certain quantity of basic MEEP + peripheral MEEP, that is to say, all those complementary works that make their operation possible (nursery unit, clean and used material supply, doctor’s office, etc.). The Functional Units group represent the ‘‘Clinical Intern Service’’ that forms part of the ‘‘Intern Area’’ together with Intensive Care, Intermediate Therapy, etc. This area, together with others such as Diagnosis and Treatment, Ambulatory Attention, Surgery, etc., form the entire building.

3. Energy-productive building modules (MEEP)

3.1. Theoretical MEEP: development and calculation of energy needs

The Theoretical MEEP represents the energy needs for the health system with different complexities. Hospital bibliography reviews fundamentally the architectural–functional approaches, the distribution, the equipment and the appropriate connection with other service areas [2–6].

The present paper further develops the methodological and systematized analysis of this information, incorporating elements of envelope quality, habitability and the typical times of use of specific equipment.

This involves calculating the energy needs of each module and its participation in the total consumption. The charts summarise the areas, basic and typical spaces, design requirements, orientation, lighting, ventilation, temperature, relative humidity, construction characteristics, equipment type and quantity, the relationships with other service areas and entry and exit flows. Consumption data of each equipment was obtained either ‘‘in situ’’, from dealers or from specific bibliography [7,8].

The Theoretical MEEP energy needs are calculated considering consumption from artificial lighting, use of equipment, and comfort conditioning.

3.1.1. Energy consumption—artificial lighting

General lighting on the module and local lighting on the working plane are analysed. The expression for the calculation is summarized in the following equation (1):

$$C_{\text{lighting}}\,(\text{kWh/day m}^2) = \text{EA}\left(\frac{1}{\eta}\right)\tau\left(\frac{1}{A}\right) \tag{1}$$

The minimum value of the luminous level (E) is determined by norm and charts according to types and use in bibliography [9]. In the case of local lighting, the luminance is calculated as a function of the area and necessary minimum luminous level (E) on the working plane. The use hours (τ) are calculated as a function of the lighting equipment daily time of use. The inverse of the local area (A) and luminous efficiency (η) are included to obtain a specific energy value for square meter of module.

For the calculation of general lighting, fluorescent lamps were used with a luminous flow of 3200 lm, a luminous efficiency (η) of 80 lm/W and a caloric efficiency (η_c) of 0.2. For local lighting, incandescent lamps and a working plane area (A) of 2 m^2 were considered.

3.1.2. Energy consumption—equipment use

Consumption values were calculated for each equipment in the module (except lighting) using the following equation (2):

$$C_{\text{equipment}}\,(\text{kWh/day m}^2) = \sum_{e=1}^{n}(n_e P\tau)\frac{1}{A} \tag{2}$$

The average energy consumption (P) is one of the most difficult values to obtain since users (professionals, technicians and staff) generally ignore it and no complete records are available. The information should either be raised equipment by equipment in the buildings or at supplier's shops. Users were consulted to establish average usage (h/day).

3.1.3. Energy consumption—comfort conditioning

To determine the comfort conditioning requirements, contributions and energy losses in a simplified energy balance are considered. The variables are: occupation, artificial lighting, equipment, direct gain through windows (DG); ventilation rate and gains and/or losses by envelope. The energy needs are represented in the following equation:

$$C_{\text{comfort conditioning}}\,(\text{kWh/day m}^2) = C_{\text{occupation}} + C_{\text{lighting}} + C_{\text{equipment}} + C_{\text{DG}} + C_{\text{ventilation rate}} + C_{\text{envelope}} \tag{3}$$

The sum of the energy demands for each variable represents the comfort conditioning demands of each MEEP (corresponding to the quantity of energy the system will supply for either heating or air conditioning purposes). The calculation of each $C_{\text{comfort conditioning}}$ term is:

I. $C_{\text{occupation}}$: heat gain from occupation.

Eq. (4) considers the heat gains from people that occupy the module

$$C_{\text{occupation}}\,(\text{kWh/day m}^2) = \text{GP}\,\tau n_{\text{p}}\frac{1}{A}\text{OF} \tag{4}$$

A constant value of 100 W was established to account for heat gain from people (GP). The occupation factor (OF) depends on the type of use of the particular service analyzed. For example, a value of 1 corresponds to an intern module (24 h occupation) and 0.3 to a consulting room (8 h).

II. C_{lighting}: heat gain from lighting.

For the value calculated in Section 3.1.1, general and local artificial lighting, the caloric efficiency (η_c) of the considered lamps is multiplied, as in the following equation:

$$C_{\text{lighting}}\,(\text{kWh/day m}^2) = C_{\text{general lighting}}\eta_c + C_{\text{local lighting}}\eta_c \tag{5}$$

III. $C_{\text{equipment}}$: heat gain from equipment.

The thermal dissipation of the equipment is considered; this consumption value has been calculated in Section 3.1.2 above.

IV. C_{DG}: heat gains by direct gain through windows (DG).

This value shows a positive correlation with variables of the climatic area, orientation, type of windows, type of protection (without protection, curtains, shutters, etc.), and opening grade. The direct solar gain values were extracted from [10]; values established for our climatic area (temperate-humid). Eq. (6) summarizes the calculated variables

$$C_{\text{DG}}\,(\text{kWh/day m}^2) = \text{DG}\,A_{\text{t}}\frac{1}{A} \tag{6}$$

All the modules were considered as a 2 m^2 window protected with a curtain and a 30% protection percentage with simple glass ($\tau = 0.8$). The orientation considered in the calculation of the direct gain through windows is East–West.

V. $C_{\text{ventilation rate}}$: heat losse due to ventilation rate.

The ventilation rate presents a significant variation as a function of each health service. The ventilation rate [n] changes according to the analyzed service. Table 1 summarizes several values.

We consider a constant air density value (ρ_a) of 1.3 kg/m^3 and an air enthalpy (J_a) of 0.99 kJ/kg K corresponding to the studied area. The air enthalpy and the heating degree days ($^\circ D$) vary according to the climatic area. For the study area (surroundings of La Plata) $^\circ D = 6$ K were considered

$$C_{\text{ventilation rate}}\,(\text{kWh/day m}^2) = Ahn\rho_a J_a^\circ D\frac{1}{A} \tag{7}$$

VI. C_{envelope}: heat losse from envelope.

The energy losses by envelope depend fundamentally on the characteristics of the construction system [11]. In (8) the losses for all types of materials that comprise the envelope (transparent and opaque) were calculated. Some thermal transmittance values (K) can be seen in Table 2

$$C_{\text{envelope}}\,(\text{kWh/day m}^2) = (K_{\text{o}}A_{\text{o}} + K_{\text{t}}A_{\text{t}})\frac{1}{A}\tau^\circ D\,\text{EF} \tag{8}$$

Regarding the construction system, a solid traditional wall (20 cm thickness, height of 3.5 m) was adopted for the calculations. An exposition factor (EF) of 1 (an exposed wall, located in an intermediate floor) was also considered.

Having completed the first instance of Theoretical MEEP (chart + database systematization), analysis of the different health facilities network was carried out. Each module was

Table 1
Ventilation rate (vol/h)

Interns/rooms/emergency	5–7
Hemotherapy	5–8
Obstetric center	15
Laboratory/X-ray	8–10
Classrooms	7
Pathologic anatomy/infectious interns	8
Intensive care	12
Surgery	10–20
Administration/consultation	5
Kitchen/offices	5

Table 2
Thermal transmittance values (W/m$_2$ K)

Walls: *K* values (W/m^2 °K)	
Common bricks 0.15 thick	2.67
Common bricks 0.20 thick	2.21
Common bricks 0.30 thick	1.88
Concrete block 0.15 thick	1.98
Hollow blocks 0.15 thick	1.98
Hollow blocks 0.21 thick	1.84
Hollow blocks 0.24 thick (double wall with air space)	1.45
Hollow blocks thick 0.21	1.42
Ceilings: *K* values (W/m^2 °K)	
Tiles, wood without insulation	2.58
Tiles, wood 1 in. insulation	1.05
Tiles, wood ceiling without insulation	0.92
Tiles, wood ceiling 1 in. insulation	0.61
Asbestos-cement board without insulation.	4.84
Asbestos-cement board with ceiling	1.06
Sheet metal, wood 1 in. insulation	0.99
Sheet metal wood ceiling without insulation	0.92
Sheet metal, wood ceiling 1 in. insulation	0.61
Reinforced concrete ceiling application	3.82
Floor tile or aluminium	
Ceramic ceiling floor tile or aluminium	1.62
Windows: *K* values (W/m^2 °K)	
Window simple glass	5.82
Window simple glass with protection (window shutter, etc.)	2.79
Solid wood door	2.61

compared with the data collected from audited hospitals, adjusting the differences between the theoretical study and the data from the real situation.

3.2. Real MEEP: development and calculation

In order to contrast theoretical studies with data collected from audited hospitals, a Real MEEP methodology was developed. The methodology for Theoretical MEEP was adapted and adjusted to the existing health facility network.

The main methodological difference between Theoretical and Real MEEP is the calculation of the artificial lighting consumption. In Real MEEP, the equations used for the calculation only considered the electric lighting installation characteristics, without verifying the performance of the theoretical demands. Luminous system thermal gain corresponds to the energy calculated in the real situation.

The energy demand in the Real MEEP was calculated using Eq. (9):

$$C_{\text{lighting}}\,(\text{kWh/day m}^2) = \sum_{e=1}^{n} (n_e P \tau) \frac{1}{A} \tag{9}$$

Significant differences were not identified for other variables. Therefore the energy needs for equipment and comfort conditioning were calculated with the same expressions as those in the Theoretical MEEP.

The methodological development and the charts construction that comprise the database, for the first two instances (Theoretical and Real MEEP) represent the largest and most comprehensive registry to date of technician-productive information in the Argentine health system. The integration of energy, production, and building construction variables, and the comparative analysis of Theoretical and Real MEEP scenarios enables us to establish (from the detailed analysis) a diagnosis of each component of the system. Energy excesses and defects could be identified and future optimizations could be proposed. The third stage involves the construction of optimal designs.

3.3. Optimized MEEP: considerations for their construction

Optimized MEEP is formulated with the intention of improving or maintaining the levels of service quality with restricted use of energy resources. The optimization involves identifying and measuring the structural variables (hygrometric and lighting comfort) and establishing retrofitting strategies with possible saving potentials.

The optimization of each differential service was determined through: (i) evaluation of the natural lighting conditions (dimension and location of windows and other lighting equipment), including minimizing the requirements for artificial sources and (ii) calculation of potential reduction in thermal loss due to different envelopes types.

3.3.1. Evaluation of natural and artificial lighting conditions

The simulation program Rough Analysis for Illuminating Spaces (RAFIS) [12] was used. This system calculates natural lighting percentages introduced in the modules taking into account the orientation and windows. The data entry is simplified, adopting a "covered sky" model. The choice of simulating with covered sky was made to analyse data from a scenario with the most unfavourable lighting conditions. The program has numeric exits and graphs representing "Natural Lighting Factor" values in a theoretical plane located at a certain height above ground [13]. These results should be contrasted with those obtained in situ for each module, and in this way we may propose design alternatives for their optimization. The evaluation is carried out for each sector of the module taking into account the different areas within that sector.

The city of La Plata (34° South Latitude) exhibits, in June, a mean exterior natural lighting measurement of 4000 lx at 08:00 and 16:00, 45,000 lx at 10:00, and 14:00 and 55,000 lx at 12:00 [14]. Natural lighting values introduced in different sectors of the module, according to the percentages established by the RAFIS program, are represented in Table 3.

Table 3
Natural lighting values according to the RAFIS program

Lab. (%)	4000 lx (8 and 16 h)	45,000 lx (10 and 14 h)	55,000 lx (12 h)
3	120	1350	1650
7	280	3150	3850
17	680	7650	9350
42	1680	18900	23100

Table 4
Artificial lighting values for general lighting, according to the percentages established by the RAFIS program

Lab. (%)	4000 lx (8 and 16 h)	45,000 lx (10 and 14 h)	55,000 lx (12 h)
General illumination			
3	$E_{gral} - 120$	$E_{gral} - 1350$	$E_{gral} - 1650$
7	$E_{gral} - 280$	$E_{gral} - 3150$	$E_{gral} - 3850$
17	$E_{gral} - 680$	$E_{gral} - 7650$	$E_{gral} - 9350$
42	$E_{gral} - 1680$	$E_{gral} - 18900$	$E_{gral} - 23100$

Table 5
Artificial lighting values for located lighting, according to the percentages established by the RAFIS program

Lab. (%)	4000 lx (8 and 16 h)	45,000 lx (10 and 14 h)	55,000 lx (12 h)
Local illumination			
3	$E_{loc} - 120$	$E_{loc} - 1350$	$E_{loc} - 1650$
7	$E_{loc} - 280$	$E_{loc} - 3150$	$E_{loc} - 3850$
17	$E_{loc} - 680$	$E_{loc} - 7650$	$E_{loc} - 9350$
42	$E_{loc} - 1680$	$E_{loc} - 18900$	$E_{loc} - 23100$

Tables 4 and 5 show the necessary artificial lighting in relation to the natural lighting percentage and to the necessary supplementary lighting (both general and local) values for each module (Theoretical MEEP). The positive values correspond to the quantity of necessary artificial lighting for each sector. The demand in general and located artificial lighting is calculated by the following equations:

$$\mathrm{Li}_{gral}\,(\mathrm{lx}) = E - E_{\%} \tag{10}$$

$$\mathrm{Li}_{loc}\,(\mathrm{lx}) = E - E_{\%} \tag{11}$$

With the artificial lighting demand (Tables 4 and 5), the necessary energy in (kWh/day m^2) can be calculated from the following equations:

$$\mathrm{Li}_{gral}\,(\mathrm{kWh/day\,m^2}) = E\frac{1}{\eta} \tag{12}$$

$$\mathrm{Li}_{loc}\,(\mathrm{kWh/day\,m^2}) = E\frac{1}{\eta} \tag{13}$$

3.3.2. Analysis of energy efficiency of building envelope

The energy loss of a building envelope depends on the thermal and constructive quality of its components. To evaluate this loss, and propose areas for possible energy savings, alternative constructive systems were proposed that would improve thermal quality. Simulations were generated using the software (EvalK) [15]. The envelope was evaluated according to the IRAM 11.605 (Instituto Argentino de Racionalización de Materiales) Norm. The software includes more than 100 constructive systems for the country's bioclimatic zones.

A standard wall of common brick, an EF (exhibition factor) of 1 and a coefficient K (thermal transmittance) of 2.67 W/m^2 K was considered. To improve conditions, more thermal insulation in the walls was proposed. Simulating incorporation of 1 in. expanded polystyrene of 20 kg/m^3 and interior termination reduced the thermal transmittance to 0.51 W/m^2 K, and the total energy consumption by 40%. Table 6 shows the results of different constructive alternatives.

Table 6
Technological characteristics for calculation

Wall	Original situation		Improved situation	
	K	kWh/day	K	kWh/day
	2.67	3.735	0.51	2.364

3.4. Environmental MEEP: methodology for the air pollutant emission evaluation

Having developed the Theoretical, Real and Optimized MEEP stages, air pollutant emissions associated with energy consumption were finally analyzed. With the energy consumption of the different MEEP, pollutant emission level was quantified for each type of energy source.

Among the emitted pollutants considered were: particulate matters 10 (PM10), sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrocarbons (Hidroc), Carbon monoxide (CO) and carbon dioxide (CO_2). The analysis was broken down by type of fuel used (fuel-oil, diesel, natural gas and packed gas).

The Energy-Productive Building Environmental Modules (MEEPA) construction made detailed measurements of energy participation and the environmental effect of each building of the network, and consequently, the Health system total consumption. A discriminated analysis of pollutant emissions led to the proposal of new strategies to improve environmental conditions (i.e., a reduction in pollutant emissions) and of habitability (hygrothermal and lighting comfort).

3.4.1. Annual energy demands

The annual energy demands were calculated from daily lighting, equipment and comfort conditioning consumption values for each MEEP and from total operating time of each health service per year [17]. Using Eqs. (14)–(16) for each variable (lighting, equipment and comfort conditioning), the

Table 7
Pollutant emission coefficients in (kg/TOE) for housing, commercial and public sectors [16]

	PM10[a]	SO_2	NO_x	Hydrocarbon	CO	CO_2
Firewood	29		0.19	0.96	308	7650
Natural gas	0.19	0.005	1.8	0.38	0.38	2120
Fuel oil	0.38	10	2.7	0.19	0.77	3050
Liquefied gas	0.19	–	1.8	0.38	0.49	2730
Intermissions	0.38	10	2.7	0.19	0.8	3130
Firewood coal	–	–	–	–	–	4500

[a] Particulate standards use PM-10 (particles less than 10 μm in diameter) as the indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 μg/m^3; the 24-h standard is attained when the expected number of days per calendar year above 150 μg/m^3 is equal to or less than one.

Table 8
Pollutant emission coefficients in (kg/TOE)

	Fuel oil		Natural gas
	Illumination	Equipment	Comfort conditioning
PM10	$PM10_{illum} = C_{illumination} \times 0.38$	$PM10_{equip} = C_{equipment} \times 0.38$	$PM10_{c.con} = C_{comfort\ conditioning} \times 0.19$
SO_2	$SO_{2_{illum}} = C_{illumination} \times 10$	$SO_{2_{equip}} = C_{equipment} \times 10$	$SO_{2_{c.con}} = C_{comfort\ conditioning} \times 0.00$
NO_x	$NO_{x_{illum}} = C_{illumination} \times 2.7$	$NO_{x_{equip}} = C_{equipment} \times 2.7$	$NO_{x_{c.con}} = C_{comfort\ conditioning} \times 1.8$
Hydrocarbon	$HIDRO_{illum} = C_{illumination} \times 0.19$	$HIDRO_{equip} = C_{equipment} \times 0.19$	$HIDRO_{c.con} = C_{comfort\ conditioning} \times 0.38$
CO	$CO_{illum} = C_{illumination} \times 0.77$	$CO_{equip} = C_{equipment} \times 0.77$	$CO_{c.con} = C_{comfort\ conditioning} \times 0.38$
CO_2	$CO_{2_{illum}} = C_{illumination} \times 3050$	$CO_{2_{equip}} = C_{equipment} \times 3050$	$CO_{2_{c.con}} = C_{comfort\ conditioning} \times 2120$

annual energy consumption in tonnes of oil equivalent (TOE) for area involved in each service can be calculated

$$C_{\text{total lighting}}\,(\text{TOE/year m}^2) = \frac{C_{\text{lighting}}}{11600} n_d 3 \tag{14}$$

$$C_{\text{total equipment}}\,(\text{TOE/year m}^2) = \frac{C_{\text{equip}}}{11600} n_d 3 \tag{15}$$

$$C_{\text{total comfort conditioning}}\,(\text{TOE/year m}^2) = \frac{C_{\text{comfort cond}}}{11600} n_d \tag{16}$$

For lighting and electromechanical equipment, the primary energy to cover that demand was considered, affecting the result with a factor of 3 corresponding to the global efficiency of the electric system (in the case of generators with steam power plant, approximately 35% of efficiency). For comfort conditioning it is applied according to the utilized energy vector.

3.4.2. Pollutant emission calculation

With the annual energy demand for each type of use (lighting, equipment and comfort conditioning) and the total of each MEEP, emission levels of each pollutant were calculated. Table 7 shows the emissions in energy kg/TOE broken down by public and/or private service sector type (residential, commercial and public) as well as by fuel used. The results of pollutant air emissions are shown in Table 8 in [kg/year m^2], which shows results of the analysis broken down by different pollutants and demand: lighting (fuel-oil); equipment (fuel-oil) and comfort conditioning (natural gas: considered fuel).

The results are incorporated in each MEEPA chart, completing the group of dimensions involved in this analysis. The outlined methodology and the development of the Energy Productive Building Modules in their Theoretical, Real, Optimized and Environmental instances has resulted in the creation of a comprehensive database that captures features of the very complex health sector in Argentina.

4. Conclusions

Current energy demand not only depends on the overall economic growth, but also on attitudes and social habits, different geographical areas and energy use activities. In this way energy production and resulting emissions has had a fundamental role in this century. The current levels of indiscriminate energy consumption are responsible for 47% of the CO_2 emissions present in the atmosphere, representing the most important factor contributing to global warming.

Taking this into account, the current methodology was developed for the MEEP calculation and its different integration levels. The aim of this study was to achieve a consistent diagnosis, identification, and optimization of variables, reduction in energy consumption, and minimization of the environmental impacts resulting from energy-inefficient structures typifying the health sector.

From the energy-environmental perspective of building and production analysis, the investigation of each health service allowed us to identify the possible savings in each area of a health facility, along with consequent emission reduction.

In addition to obtaining a thorough diagnosis, the current methodology makes it possible to diagnose and compare the current situation of each MEEP with proposed improvements. It thus becomes possible to apply guidelines to improve real MEEP with the objective of optimizing conditions of habitability (hygrothermic and lighting comfort), enable the evaluation of new energy needs, and quantify of emissions per pollutant and type of fuel.

The development of the Theoretical and Real MEEP instances allowed us to adjust the interaction between variables and to quantify the levels of divergence between standard values and those obtained in situ.

The present methodology stands for comparing homologous productive sectors and the corresponding building within the network of an urban area. The energetic load of each module in a specific building can be evaluated as well as its integration within the network, detecting urban areas of concentrated consumption, insufficiencies of infrastructure etc. Understanding the dynamics of these nodes of the network allows us, in this case, to form a diagnosis of energetic demands of the health sector within the global building network.

The present method of analysis and the results obtained represent the first approach to propose energy-productive building modules that relate and integrate energy use, building/construction, and production variables applied to the health services sector. The development of a database has made it possible to present results in a permanent and consistent way, establishes design standards, and compares and resolves dispersions between equivalent situations. This database promises to become a useful tool for referencing current knowledge regarding optimization and design of standards.

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