Recibido 26/02/2021
Aceptado 10/06/2021

ENERGY EFFICIENCY IMPROVEMENTS IN HEATING. POTENTIAL FOR INTERVENTION IN AN EXISTING SCHOOL BUILDING IN THE METROPOLITAN AREA OF SAN JUAN, ARGENTINA.

MEJORAS DE EFICIENCIA ENERGÉTICA EN CALEFACCIÓN. POTENCIAL DE INTERVENCIÓN EN EDIFICIO ESCOLAR EXISTENTE DEL ÁREA METROPOLITANA DE SAN JUAN, ARGENTINA

MARÍA GUILLERMINA RÉ
Magister en en Arquitectura en Zonas Áridas y Sísmicas
Becaria Doctoral CONICET, Docente, Investigadora en Instituto
Provincial de Planeamiento y Hábitat, Facultad de Arquitectura,
Urbanismo y Diseño Universidad Nacional de San Juan
San Juan, Argentina
https://orcid.org/0000-0002-3109-7138
guillerminare@gmail.com

MARÍA PÍA MAZZOCCO
Arquitecta
Profesional independiente
Córdoba, Argentina
https://orcid.org/0000-0002-3403-1353
piamazzocco@gmail.com

CELINA FILIPPÍN
Doctora en Ciencias
Investigadora Principal
Consejo Nacional de Investigaciones Científicas
y Técnicas (CONICET)
La Pampa, Argentina
https://orcid.org/0000-0002-0521-6180
cfilippin@cpenet.com.ar

RESUMEN

El cambio climático, el constante crecimiento del consumo energético y los altos niveles de emisiones que registra el sector energético, requieren de la implementación de soluciones concretas. La rehabilitación de edificios ofrece una oportunidad significativa para contribuir en este aspecto. El objetivo del presente trabajo es analizar el potencial de intervención en un edificio escolar perteneciente al Programa Nacional 700 Escuelas. Las mejoras en eficiencia energética se evalúan a través de simulación dinámica y se calculan indicadores respecto al consumo anual de energía para calefacción. Los valores para el edificio de referencia son de 74,5 kWh/m2 año y de 158 kWh/alumno. Con las propuestas de rehabilitación se podrían alcanzar ahorros energéticos de entre 39,7% y 60%. La alternativa R-Media se presenta como la más conveniente al lograr beneficios energéticos del 47%, con menores costos de inversión. Los indicadores de eficiencia energética para dicho conjunto de mejoras son de 39,2 kWh/m2 año y de 83,1 kWh/alumno. Los resultados alcanzados pueden servir de referencia para la rehabilitación de 71 edificios escolares erigidos en la provincia de San Juan entre los años 2004 y 2015, los cuales responden a una tipología constructiva con similitudes de materialización de la envolvente y configuración funcional.

Palabras clave
escuelas, rehabilitación energética, eficiencia energía, simulación.

ABSTRACT

Climate change, the constant growth of energy consumption, and the high levels of emissions recorded by the energy sector, require the implementation of concrete solutions. Building rehabilitation offers a significant opportunity to contribute in this regard. The purpose of this work is to analyze the potential for intervention in a school building from the "Programa Nacional 700 Escuela" (National 700 Schools Program). The improvements in energy efficiency are evaluated through a dynamic simulation and indicators are calculated regarding the annual energy consumption for heating. The values for the reference building are 74.5 kWh/m2 year and 158 kWh/student. With the rehabilitation proposals, energy savings could be achieved of between 39.7% and 60%. The R-Mean alternative appears as the most convenient one as it achieves energy benefits of 47%, with lower investment costs. The energy efficiency indicators for said set of improvements are 39.2 kWh/m2 year and 83.1 kWh/student. The results achieved can serve as reference for the rehabilitation of 71 school buildings built in the province of San Juan between 2004 and 2015, which belong to a construction typology with a similarity of materials of their envelope and functional configuration.

Keywords
schools, energy rehabilitation, energy efficiency, simulation

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 20 -31
https://doi.org/10.22320/07190700.2021.11.01.02

INTRODUCTION

The construction industry and building operation have the highest share in energy use and associated carbon dioxide emissions. During 2017, they represented 36% of final energy consumption, with a CO_2 production of 39% (IEA, 2018). Currently, there is a growing interest of countries in their state policies, to improve the performance of the building sector. In Argentina, the IRAM 11900 Standard (2017) constitutes progress in regulatory matters, although it is limited to residential use.

The energy retrofitting of buildings can be achieved by applying bioclimatic design strategies, improving the thermal properties of the envelope, replacing equipment for more efficient ones, and using passive or hybrid climate control systems that involve renewable energies (Esteves, 2017). Likewise, improvements of vertical and horizontal enclosures, with the incorporation of insulation materials, represent an investment in the quality of the infrastructure (Andersen, Discoli, Viegas & Martini, 2017; Camporeale, Mercader y Czajkowski, 2017; A. Esteves, M. Esteves, Mercado, Barea & Gelardi, 2018, Kuchen & Kozak, 2020).

The intervention potential for school building envelopes generates a two-fold benefit: improving energy efficiency and optimizing thermal comfort levels. Schools must guarantee indoor environmental quality standards, so that students and teachers can properly experience teaching-learning processes (San Juan, 2014, Barbosa, De Freitas & Almeida, 2020).

Energy efficiency in buildings is measured using consumption units per area (kWh/m^2 year). This indicator allows making comparisons at a domestic and international level. However, for school buildings it has shortcomings, like the exclusion of usage. Schools comprise, as is well known, spaces with diverse characteristics. The energy consumption must also be defined considering the occupation of spaces (kWh/student). On adopting a combination of both energy efficiency indicators, a more complete image is obtained (Sekki, Andelin, Airaksinen & Saari, 2016). In particular, one study in Brazil (Geraldi & Ghisi, 2020) determined that the energy use intensity indicator considering the number of students, is more reliable and suitable to represent the stock of school buildings.

The energy behavior assessment of existing buildings and retrofitting proposals, can be addressed using different complementary approaches (Wang, Yan, & Xiao, 2012). In this sense, dynamic simulation is a favored tool to analyze building operation in their post-construction stage, as it provides the possibility to identify the different parameters that affect energy consumption and quantify their impact on the total values (Veloso & Souza, 2019).

Given this context, the main purpose of this work is to assess energy wise, the intervention potential of a traditional school building, located in the Metropolitan Area of San Juan (AMSJ, in Spanish), using a dynamic simulation. The specific goals seek, first of all, to generate the thermal-physical model of the building, starting from the calibration with the measured energy consumption values; and second, studying different technological and solar energy collector proposals, to reduce energy consumption while keeping comfort; and, third, calculating Energy Efficiency Indicators (EEI).

METHODOLOGY

Work is done based on an applied research, progressing through a case study. A large part of existing school infrastructure, appears as an opportunity to reverse the environmental issue of energy use, if considered as networks instead of independent entities (Boutet, Hernández, Jacobo, 2020). For this study, a representative school building is chosen due to its operational setup and construction technology (Ré, 2017): the Provincial School of Rivadavia (CPR, in Spanish), is part of the National 700 Schools Program (PN700E, in Spanish), valid between 2004 and 2008, and extended through the More Schools (Más Escuelas) program, to 2015. In the Province of San Juan, 71 public schools, which have been built within the framework of these programs, could have energy retrofitting.

The analysis is made in the cold season, on being a critical period for climate control in a school building, given its greater use. Considering the diagnosis, different energy efficiency improvement proposals are made and their assessment is made through a dynamic simulation using the Ecotect software (Autodesk, 2011).

The existing building in its original envelope, equipment and behavior conditions, is called "reference building". This expression is used internationally in stock research and energy retrofitting proposals (Attia, Shadmanfar & Ricci, 2020; Geraldi & Ghisi, 2020).

CLIMATE CHARACTERIZATION AND LOCATION

The city of San Juan is located at 640 masl, and its geographic coordinates are: 31°32'13" S 68°31'30" W. It belongs to the bioenvironmental III-a warm template zone, according to the classification of the IRAM 11603 Standard (2012) for the Republic of Argentina (Table 1). Subzone "a" has daily and

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 20 -31
https://doi.org/10.22320/07190700.2021.11.01.02

Climate data		Unit	Winter	Summer
Temperature	Mean	°C	10,61	25,56
	Max. Mean		18,5	33,1
	Min. Mean		2,7	18
	Design Max.		-	41,4
	Design Min.		5,6	-
Relative humidity		%	58	46,7
Rainfall	Mean	mm	13	60,2

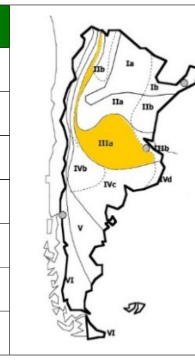

Table 1. Climate data of San Juan. Maps of the geographic location and Bioenvironmental Zone III.a. Source: Preparation by authors based on data from IRAM 11603 Standard (2012). Map: Wikipedia (2020).

Variable	Un.	January	February	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Mean T°	°C	26,49	26,46	21,59	19,53	15,37	13,16	9,82	12,75	13,88	21,28	23,92	28,09
Max T°	°C	31,34	31,71	26,25	24,62	20,57	18,31	14,75	18,88	19,35	26,64	29,65	33,23
Min. T°	°C	21,36	21,16	16,89	14,33	10,41	7,83	5,09	6,76	8,51	15,60	17,91	22,47
Relative humidity	%	45	37	46	46	47	38	44	32	37	34	32	36
Solar Radiation	W/m2	311	320	248	206	153	125	126	166	200	281	324	355
Atmospheric pressure	kPa	93,73	93,60	93,90	93,94	93,98	94,12	94,27	94,26	94,22	93,81	93,64	93,47
Wind speed	m/s	2,85	2,96	2,99	2,00	2,10	1,94	2,14	2,39	2,99	3,06	3,26	3,32
Dew point	°C	12,60	10,18	8,54	6,93	3,40	-1,67	-2,69	-4,78	-1,42	3,14	4,48	10,55
Wet bulb T°	°C	26,37	25,79	20,66	18,56	14,21	11,02	7,82	10,66	12,07	19,69	22,31	27,36

Table 2. Monthly average climate variables of 2013. Source: Preparation by authors based on the data of Pontoriero (2017).

seasonal thermal amplitudes, that are equal or greater than 14°C.

A climate file of the year under study was prepared to simulate the energy performance of the school building, which allows a closer approach to reality. The information was processed and transcribed into the Elements program (Rocky Mountain Institute [RMI], 2020). The climate data of San Juan was obtained with a meteorological station located in the Electricity Institute (Pontoriero, 2017). Table 2 shows the information input into the program.

CASE STUDY

The Provincial School of Rivadavia is a state-run secondary school. The school has a ground floor, with a covered surface area of 1169.4 m^2 and a heated surface of 604.38 m^2. The circulation areas are semi-covered, using corridors. The construction technology is baked large brick masonry walls, with 30 cm or 22 cm bonds, and plaster on the outside. The upper horizontal enclosure is made from reinforced flat or sloped concrete slabs, with a tile finish (classroom sector). It has sliding woodwork, of a steel sheet frame and single glazing. The windows have north and west facing shutters (Figure 1).

In the diagnosis stage, the shading range is analyzed from 9am to 5pm, every 30 minutes, for June 21st, with the goal of studying the potential solar gain that the building has (Figure 2). The classrooms (all north-south facing), have crossed ventilation and natural lighting. However, the north-facing shutters restrict entry of sunlight in winter, on remaining relatively closed most of the time.

The thermal-energy assessment of school buildings significantly differs from other uses and merits considering other aspects, like:

- Occupation: 285 students spread over the morning and afternoon sessions.
- Maximum gross occupation density per classroom and per session: 2.29m^2/student; value that corresponds to 24 students per 55m^2 classroom.
- Ventilation rate per classroom, as per ANSI/ASHRAE Standard 62.1 (2019): 551m^3/h.classroom or 23m^3/h.student
- Building use time: 8 h from Monday to Friday; 6 h on Saturday.

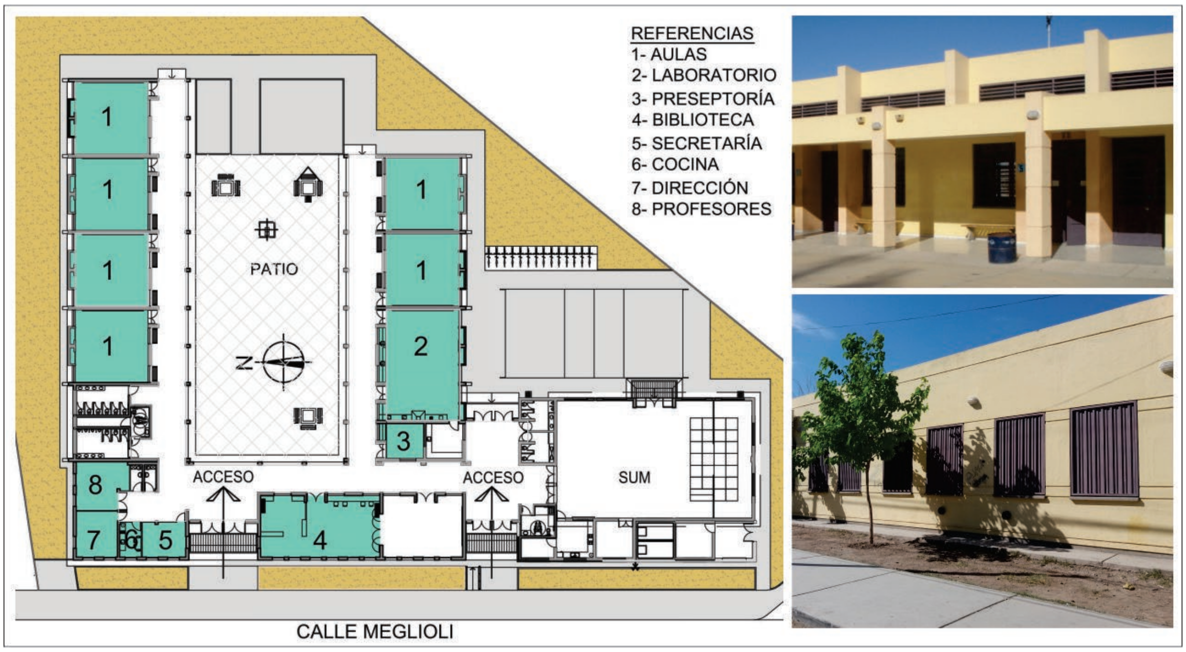

Figure 1. Floor plan of CPR, with identification of spaces with mechanical heating (in green). Photographs of the corridor and front of the building with the shutters. Source: Preparation by the authors.

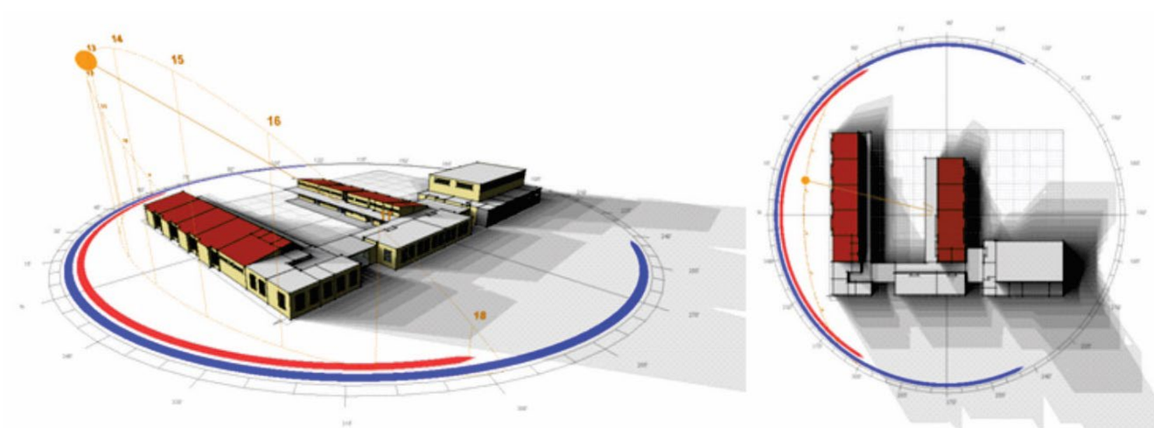

Figure 2. Building volumetry. Shading analysis for June 21st. Source: Preparation by Authors with Ecotect.

DYNAMIC ASSESSMENT

The reference building and the different retrofitting proposals are evaluated using dynamic simulation with Ecotect . The software makes the comprehensive and simultaneous analysis of sunlighting, internal gains, geometric and construction elements technological setup, possible. Ecotect allows studying the intervention potential of construction solutions by modifying the existing condition, and individualizing different areas of the building to get to know their energy performance. Different authors who currently use the program, have concluded that the results obtained are fair, considering the data measured and simulated (Trisnawan, 2018; Khan, Asif & Mohammed, 2017; Harish & Kumar, 2016).

To provide reliability and validity to the simulation results, the calibration of the IT model was done using empirical data (Godoy-Muñoz, 2015). The electricity and natural gas consumption records of the school

1 ECOTECT used a simplified calculation based on the Admittance Method of the Chartered Institute of Building Services Engineers (CIBSE Admittance Method). It applies the admittance of construction elements and thermal attenuation and delay factors of materials to define the transitory system.

Heating energy consumption							
Two-month period	1	2	3	4	5	6	Anual
Natural Gas Consumption							kWh
Cooker/Oven	292	667	697	712	622	508	3498
Heating (VF heaters)	11	3630	19491	13714	7719	_	44565
Total Gas	303	4297	20188	14426	8341	508	48063
Electricity Consumption							
Quartz Space Heater	_	68	141	95	_	_	304
Heating Fans	_	185	378	251	_	_	814
Electrical heating	_	253	519	346	_	_	1118
Other uses	7412	10026	7007	7597	6280	6266	44588
Total Electricity	7412	10279	7526	7943	6280	6266	45706
Total Heating	11	3883	20010	14060	7719	_	45683

Table 3. Natural gas and electricity consumption of the building. Heating consumption discriminated by energy source. Source: Preparation by the Authors.

corresponding to the energy audit of 2013 were used (Ré, Blasco Lucas y Filippín, 2016).

The climate control system adopted for the simulation is "heating only" in the rooms with heaters, and "full air-conditioning" for the space that has a split Air Conditioning (AC) unit.

ENERGY CONSUMPTION

The energy analysis focused on the building's operation phase (operative energy). The consumption data was obtained from service bills and the energy audit. The natural gas records, in m^3, are converted into kilowatt hours (kWh). A conversion factor of 9,767 kWh/m^3 is used, which comes from considering the Lower Heating Value of the natural gas (8400 $kcal/m^3$) and an equivalent of 1 kW to 859.9 kcal/h (Selectra, 2020).

The electrical equipment for climate control the school has is: 2 heating fans (1500 W), 1 quartz space heater (1200 W) and 1 AC (2150 W) in the administration sector. In the classrooms, there are wall fans (90 W). The natural gas heating devices are 10 vent-free gas heaters of 5700 kcal/h and 4 of 3800 kcal/h.

Gas consumption for heating is 44,565kWh/year. The electricity used to heat the rooms is calculated at 1,118 kWh, according to the power and hours of use of devices (ENRE, 2020). Table 3 shows each consumption by two-month period, using the information from the service bills.

RETROFITTING PROPOSALS

Using what has been seen, energy retrofitting proposals for the school building are prepared as thermal-energy behavior optimization measures. These involve: increasing the area of direct solar gain (DSG) in the classrooms on the north corridor; increasing the thermal resistance of the envelope; and efficiency improvements in the mechanical climate control system.

The increase of the collector area is applied to the north corridor classrooms due to their potential for intervention. The values reached represent 13% of the effective glazed area compared to the useful area of the classroom. The windows pass from 5.15m^2 (reference building) to 7.04m^2 (rehabilitated case). In addition, the decision was made to eliminate the shutters on this side, so that solar gains are not reduced in winter.

The thermal properties of the vertical and horizontal enclosures are calculated using the procedures of the IRAM 11601 Standard (2002). The improved elements confirm the thermal transmittance values suggested in IRAM 11605 (2002) in comfort levels A – *recommended* and B – *medium*. An External Thermal Insulation System (ETIS) is used for wall retrofitting. The existing woodwork is replaced by doors and windows that allow increasing the effective glazed area, improving thermal properties, and reducing air infiltrations. The substitution is foreseen in all the heated spaces of the building. At level A, aluminum frames are used with a thermal bridge breaker (TBB) and hermetically sealed double glazing (HDG 6-12-6 mm). In level B, a simple frame with HDG is used.

The construction improvements are grouped into different intervention proposals, which have the following names: Simple Retrofit (Simple-R) A and B, Medium Retrofit (Medium-R) and Optimal Retrofit (Optimal-R). Table 4 shows the makeup of each group,

Technological Component	Properties	Reference Building	Simple-R B	Simple-R A	Medium-R	Optimal-R
Woodwork		Sheet metal	Aluminum	Aluminum + TBB	Aluminum	Aluminum + TBB
	Material	V. Simple (6 mm)	DVH (6-12-6 mm)	DVH (6-12-6 mm)	DVH (6-12-6 mm)	DVH (6-12-6 mm)
	U [W/m2.K]	5.66	3.89	2.82	3.89	2.82
Wall 1	Material	Brick + plaster	Brick + plaster	Brick + plaster	EPS 50 mm + plaster	EPS 100 mm + plaster
	Thickness [cm]	30	30	30	35	40
	U [W/m2.K]	2.04	2.04	2.04	0.49	0.28
Wall 2	Material	Brick + plaster	Brick + plaster	Brick + plaster	EPS 50 mm + plaster	EPS 100 mm + plaster
	Thickness [cm]	22	22	22	27	32
	U [W/m2.K]	2.47	2.47	2.47	0.51	0.28
Sloped slab	Material	Slab H° A°+ mix + tiles	EPS 100 mm + galvanized sheet	EPS 150 mm + galvanized sheet	EPS 100 mm + galvanized sheet	EPS 150 mm + galvanized sheet
	Thickness [cm]	30 cm	40.2	45.2	40.2	45.2
	U [W/m2.K]	1.35	0.26	0.18	0.26	0.18
Flat slab	Material	Slab H° A°+ mix + membrane	EPS 100 mm + mix + membrane	EPS 150 mm + mix + membrane	EPS 100 mm + mix + membrane	EPS 150 mm + mix + membrane
	Thickness [cm]	26 cm	39 cm	44 cm	39 cm	44 cm
	U [W/m2.K]	1.43	0.26	0.18	0.26	0.18
U Global [W/m2.K]		**2.26**	**1.54**	**1.35**	**0.98**	**0.71**

Table 4. Technological components. Materials, thermal properties. Reference building and retrofitting proposals. Source. Preparation by the authors.

with their respective thermal transmittances (U). For air renewals, a rate of 2.6 is considered, the value established to guarantee healthy hygienic conditions (ANSI/ASHRAE, 2019).

The investment costs and Amortization Period (AP) are also analyzed, aspects that contribute in decision making. Said estimation could have significant variations in the future due to the high inflation seen in the country over the last decade, and likewise, on facing possible changes in government policy for energy subsidies, a situation that is currently happening.

The third strategy is improving the heating system efficiency. The replacement of individual equipment is proposed (vent-free heaters) that have an efficiency of 59%, according to the IRAM 11900 Standard (2017), with a central heating system whose estimated efficiency is 65%.

The savings potential is analyzed using two Energy Efficiency Indicators: kWh/m^2 year and kWh/student, for the total of the heated building (604.38m^2), and for the 4 classrooms on the north corridor (200m^2). The number of students is 285 and 192, respectively.

RESULTS AND DISCUSSION

Figure 3 presents the calibration of the reference case's computation model using the energy records. The real heating energy consumption is compared with the values calculated in the simulation. The scatter graph shows a R^2 = 0.956 ratio, which is statistically significant ($P \leq 0.05$). It is considered that the model obtained can be used to study the behavior of the different technologies proposed.

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 20 -31
https://doi.org/10.22320/07190700.2021.11.01.02

2-month period	Data measured	Data simulated
	Heating consumption (kWh)	
1 (feb-mar)	11	1.479
2 (apr-may)	3.883	5.191
3 (jun-jul)	20.010	21.367
4 (aug-sep)	14.060	15.722
5 (oct-nov)	7.719	1.259
Total	45.683	45.018

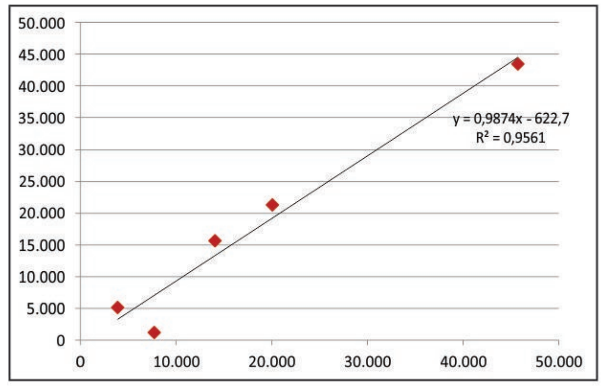

Figure 3. Energy consumption for heating. Data measured in 2013 vs. simulated. Source: Preparation by Authors.

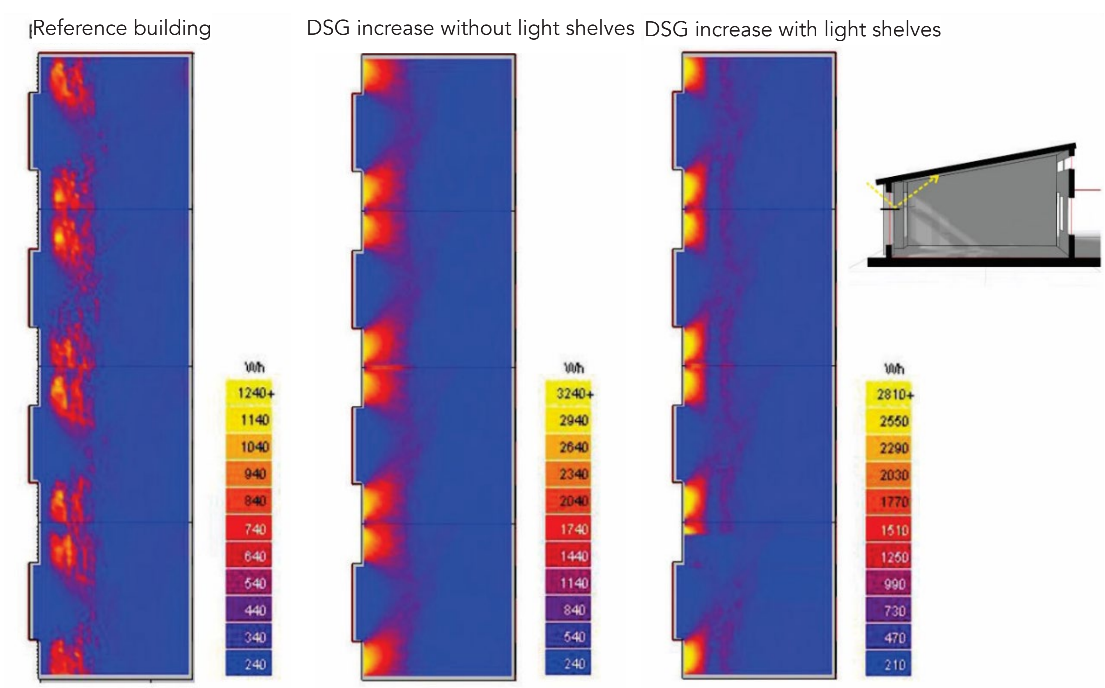

Figure 4. Impact of average daily radiation on north corridor classrooms. Reference building and Optimal-R. Source: Preparation by the Authors with Ecotect.

ENERGY EFFICIENCY IMPROVEMENTS

In north-facing classrooms, the average daily radiation in winter is analyzed on a work plane located 80 cm from the ground (Figure 4). In the image on the left, the windows of the reference building with open shutters can be seen. In the center, the Optimal Retrofit with an increase of the direct solar gain surface and removal of the shutters. In order to mitigate glare, fixed light shelves are placed, which generate a uniform distribution in the classroom space (Figure 4, right); and to avoid undesirable heat gains, an eave is generated with the sloped roof, which provides shading in warm months.

Possible overheating in summer is evaluated through the simulation. Thus, the cooling energy consumption calculation is made for the 4 classrooms being worked on, with a system efficiency of 3.6 according to the IRAM Standard (2017). The results show a consumption of 3,871 kWh/year for the reference building during the summer period (from October to March). The retrofitted cases would consume 3,338 kWh/year Optimal-R, and 3,360 kWh/year Optimal-R + DSG, confirming that the mechanical climate control requirement is not increased.

The heating energy consumption for the reference building, and for the different retrofits can be seen in Figure 5. The EEI for each case can be seen on the same graph. The consumptions simulated with the existing vent-free (VF) heaters are represented in blue, and the central heating (CH) system, in green.

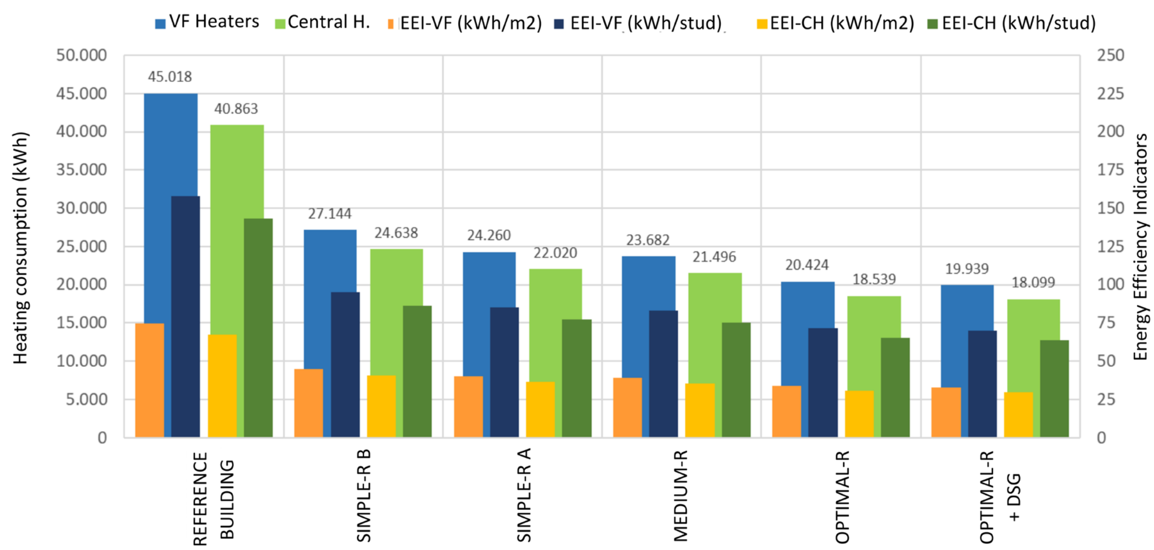

Figure 5. Heating energy consumption for reference building and retrofit proposals. Source: Preparation by the Authors.

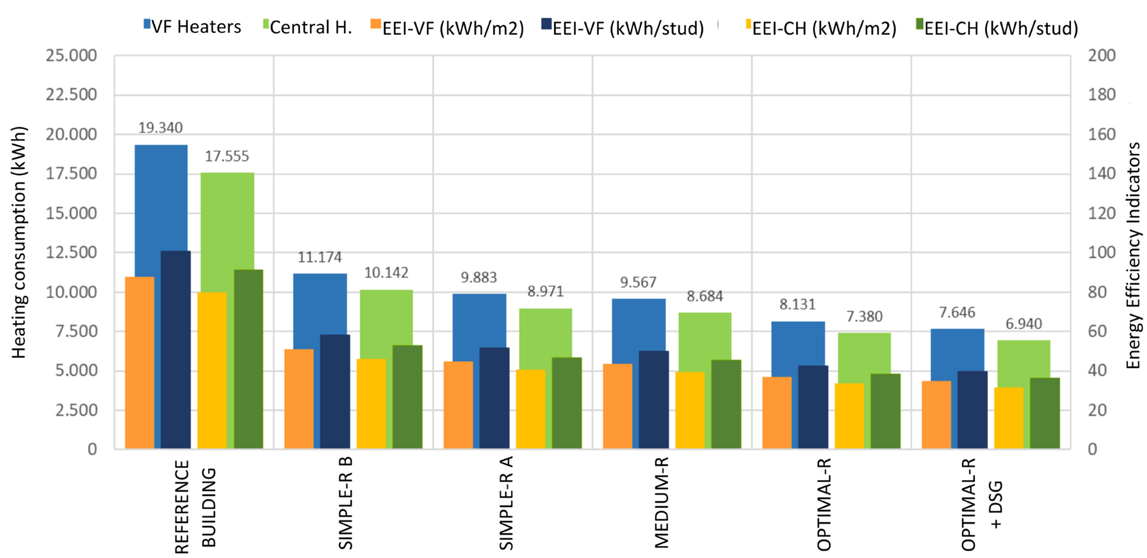

Figure 6. Heating energy consumption of the north corridor classrooms sector. Source. Preparation by the Authors.

The reference building reduces its consumption from 45,018 kWh/year to 40,863 kWh/year with a change of equipment, representing a saving of 9%.

With the increase of the envelope's thermal resistance, the energy consumption falls from 27,144 kWh/year (Simple-R B-VF) to 18,539 kWh/year (Optimal-R-CH). The EEI-VF for these cases is 44.0 kWh/m² and 95.2 kWh/student, and EEI-CH is 30.7 kWh/m² and 65.0 kWh/student. The Optimal-R model with an increase of the Direct Solar Gain (DSG) and central heating system, shows an energy performance of 18,099 kWh/year with a consumption reduction of 60%. In this proposal, the EEI falls from 74.5 kWh/m² and 158 kWh/student (reference building) to 29.9 kWh/m² and 63.5 kWh/student.

The intervention potential of the four north-facing classrooms can be seen in Figure 6. This zone could reduce its consumption from 19,340 kWh/year to 6,940 kWh/year, if the 3 proposed strategies were applied. The EEI range from 87.9 kWh/m² and 100.7 kWh/student (EEI-VF Reference Building) to 31.5 kWh/m² and 36.1 kWh/student (EEI-CH Optimal-R + DSG). The Energy Efficiency Indicators per student for the classroom sector have significantly lower values than

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 20 -31
https://doi.org/10.22320/07190700.2021.11.01.02

Variant analyzed	EEI-VF	EEI-VF	Consumption	Cost per year	Value/surf	Total Retro	Total Retro	Amortization
Case	kWh/m2	kWh/alumno	kWh/año	$	U$/m2	U$	$	Años
Ref. building	74,5	158,0	45.018	52429				
Simple-R B	44,9	95,2	27.144	31613	108	65.296	6.298.848	55
Simple-R A	40,1	85,1	24.260	28254	153	92.301	8.923.369	67
Medium-R	39,2	83,1	23.682	27581	127	76.953	7.406.979	54
Optimal-R	33,8	71,7	20.424	23787	182	109.787	10.614.726	67
Optimal-R+DSG	33,0	70,0	19.939	23222	191	115.364	11.132.611	69

Table 5. Comparison of EEI, energy costs, and value of the investment for the envelope retrofit proposals. Dollar US$1 = $96.5 at 26/05/2021, Banco Nación Argentina. Source: Preparation by the Authors.

National 700 Schools Program in AMSJ	EEI - surface	EEI - density
Units of analysis	kWh/m2	kWh/student
Escuela Técnica Obrero Argentino	32,2	81,6
Escuela Provincial Educación Técnica N°5	33,6	101,0
Colegio Provincial de Rivadavia	75,6	160,3
Colegio Secundario Jorge Luis Borges	24,9	61,6
Colegio Superior N°1 Rawson	28,2	35,5

Table 6. EEI of Schools belonging to PN700E of the Metropolitan Area of San Juan. Source: Preparation by the Authors.

those for the entire building. These represent the differentiated use intensity that characterize school typology buildings.

The improvements proposed are analyzed below from the economic aspect. The consideration of the investment costs per surface unit (US$/m^2) and the Amortization Period help in the decision making. The comparison of the EEI with the AP allow identifying that the Simple-R B and Medium-R improvements are the most suitable to allow reducing energy consumption with a moderate investment (Table 5). The Optimal-R + DSG has the greatest energy saving, but has high construction values (US$191/m^2), conditioned by the cost of the technological components. The aluminum windows with TBB, double the value of those that do not have them. The alternative Medium-R reduces the energy demand by 47%, with investment costs of US$127/m^2. The heating energy consumption indicators for this set of improvements are 39.2 kWh/m^{2}year and 83.1 kWh/student.

It is warned that the AP is higher in the number of years, due to the low energy costs at a national level, where both natural gas and electricity are subsidized. In addition, their value did not match the significant increase in annual inflation seen in recent years. However, the energy efficiency improvements proposed in this work are justified from an environmental and social point of view, within CO_2 emissions reduction policies, and indoor thermal comfort improvements during the building's service life. It is considered that, in school typologies, where the education and training of future generations takes place, that the suitable conditions of the classroom, and the reduction of the energy demand, exceed the business vision regarding the return on investment.

HEAT LOSSES AND GAINS

The energy losses through opaque enclosures and openings, for a typical day in July are also analyzed using the simulation software. The heat losses through convection and air infiltration between the Reference Building and Optimal-R are compared. The study reveals that the proposed improvements achieve a reduction of 29.2% and 37.6%, respectively.

Regarding thermal gains, it is seen that the increase of the collector area in the north-facing classroom sector represents a contribution of 6%. The internal loads (people, lighting, equipment) show a heat contribution of between 56% and 61% in the retrofit proposals.

ENERGY EFFICIENCY INDICATORS

The EEI of CPR, are compared with the energy behavior that other school buildings of the PN700E located in the Metropolitan Area of San Juan, show. The data of Table 6 express the energy consumption indicators by surface unit and by student, calculated based on real records obtained from service bills. It can be seen that the school analyzed has the highest values, which justifies the need for retrofitting.

The results attained in this study could be transferred to improve the energy performance and the indoor thermal comfort conditions of other school infrastructure from the national programs implemented in the province between 2004 and 2015.

CONCLUSION

The work presented allowed analyzing the intervention potential of different retrofitting proposals. Concretely, the Optimal-R + DSG incorporates improvements in the thermal transmittance of the envelope (Global U of 0.71 W/m^{2}K), direct solar gain in north-facing classrooms, and efficiency of the heating system. This set verifies the Level A defined by IRAM 11605 (2002), and reduces the energy consumption by 60% compared to the reference building. The Medium-R, with Global U values of 0.98 W/m^{2}K, attains Level B of the Standard, and shows potential energy savings of 47% compared to VF heaters. Said proposal is the most convenient alternative after comparing potential energy consumption, investment costs, and the amortization period.

The energy efficiency indicators calculated for the retrofitted building, give an annual heating energy consumption range from 44.9 kWh/m^{2}year to 33 kWh/m^{2}year and of 95.2 kWh/student to 70 kWh/student. The values for the reference building are of 7.45 kWh/m^2 year and 158 kWh/student, in the simulation model.

The data allow acknowledging the importance of considering gains from radiation and internal ones in densely occupied spaces like school classrooms, for a better approximation to the auxiliary annual heating load value, in analytical calculations and of a seasonal system.

Facing the new reality brought on by the Covid-19 pandemic, and facing possible epidemics that involve climate control regarding disease transmission, ASHRAE (2020) recommends, in the case of schools, to increase classroom ventilation with a suitable outside air supply, that allows diluting contaminants. This situation encourages the scientific sector to perfect considerations on energy consumption.

Likewise, considering the new health demands in school buildings, the need is clear to revise and update the School Architecture Basic Regulations and Criteria (Ministry of Education, 1998). Among the different aspects that merit being checked, the recommended values for air renewals and room ventilation are highlighted, as these directly affect people's health.

ACKNOWLEDGMENTS

The National University of San Juan and IRPHa-CONICET are thanked for their contributions in financing the research, within the framework of the CICITCA 2020 project (Code A0948). The work forms part of the Doctoral Thesis of the Author, María Guillermina Ré, from the Doctorate in Architecture of the University of Mendoza.

BIBLIOGRAPHICAL REFERENCES

Andersen, M., Discoli, C.A., Viegas, G.M. y Martini, I. (2017). Monitoreo energético y estrategias de retrofit para viviendas sociales en clima frío. *Hábitat Sustentable*, *7*(2), 50-63. DOI: https://doi.org/10.22320/07190700.2017.07.02.05

ANSI/ASHRAE (2019). *Standard 62.1-2019. Ventilation for Acceptable Indoor Air Quality*. ASHRAE and the American National Standards Institute.

ASHRAE (2020). *Reopening of schools and universities*. Recuperado de https://www.ashrae.org/technical-resources/reopening-of-schools-and-universities

Attia, S., Shadmanfar N. y Ricci, F. (2020). Developing two benchmark models for nearly zero energy schools. *Applied Energy* 263, art. 114614. DOI: 10.1016/j.apenergy.2020.114614

Autodesk (2011). *Ecotect Analysis. Sustainable Building Design Software*. Recuperado de www.autodesk.com/ecotect-analysis.

Barbosa, F.C., De Freitas, V.P. y Almeida, M. (2020). School building experimental characterization in Mediterranean climate regarding comfort, indoor air quality and energy consumption. *Energy & Buildings*, *212*. DOI: 10.1016/j.enbuild.2020.109782

Boutet, M.L., Hernández, A. y Jacobo, G. (2020). Methodology of quantitative analysis and diagnosis of higro-thermal and lighting monitoring for school buildings in a hot-humid mid-latitude climate. *Renewable Energy*, *145*, 2463-2476. DOI: 10.1016/j.renene.2019.08.009

Caporeale P.E, Mercader Moyano, M. P. y Czajkowski, J. D. (2017). Multi-objective optimisation model: A housing block retrofit in Seville. Energy & Buildings, 153, 476–484. 10.1016/j.enbuild.2017.08.023

ENRE (2020). Ente Nacional Regulador de la Electricidad. Ministerio de Desarrollo Productivo. Recuperado de https://www.argentina.gob.ar/enre/uso-eficiente-y-seguro/consumo-basico-electrodomesticos.

Esteves, A. (2017). *Arquitectura bioclimática y sustentable: Teoría y práctica de la conservación de la energía. Sistemas solares pasivos y enfriamiento natural de edificios*. Mendoza: FAUD, UM; INHAE, CCT-CONICET.

Esteves, A., Esteves, M.J., Mercado, M.V., Barea, G. y Gelardi, G. (2018). Building Shape that Promotes Sustainable Architecture. Evaluation of the Indicative Factors and Its Relation with the Construction Costs. *Architecture Research*, *8*(4), 111-122. DOI:10.5923/j.arch.20180804.01

Geraldi, M. S. y Ghisi, E. (2020). Mapping the energy usage in Brazilian public schools. *Energy & Buildings*, *224*, 1-17. DOI=10.1016/J.ENBUILD.2020.110209

Godoy-Muñoz, A. (2015). *Validación y calibración de la simulación energética de edificios La importancia del análisis de sensibilidad e incertidumbre*. Tesis de Doctorado en Sostenibilidad, Universidad Politécnica de Catalunya.

Harish, V. S. K. V. y Kumar, A. (2016). A Review on Modeling and Simulation of Building Energy Systems. *Renewable and Sustainable Energy Reviews*, *56*, 1272–1292. DOI: 10.1016/j.rser.2015.12.040

IEA (2018). *Informe Global. Hacia un sector de edificios y de la construcción eficiente, resiliente y con cero emisiones. Global Alliance for Buildings and Construction (GlobalABC)*. Coordinado por el Programa del Medio Ambiente de las Naciones Unidas. Recuperado de www.iea.org.

IRAM (2002). *11605. Acondicionamiento térmico de edificios. Condiciones de habitabilidad en Edificios*. Revisión 2002. Instituto Argentino de Normalización.

IRAM (2002). *11601. Aislamiento térmico de edificios. Métodos de cálculo*. Instituto Argentino de Normalización.

IRAM (2012). *11603. Acondicionamiento térmico de edificios. Clasificación bioambiental de la República Argentina*. Instituto Argentino de Normalización.

IRAM (2017). 11900. Prestaciones energéticas en viviendas. Método de cálculo. 2° Edición. Instituto Argentino de Normalización.

Khan, H.S., Asif, M. y Mohammed, M.A. (2017). Case Study of a Nearly Zero Energy Building in Italian Climatic Conditions. *Infrastructures*, *2*(4), 19. DOI: 10.3390/infrastructures2040019

Kuchen, E. y Kozak, D. (2020) Transición energética argentina. El nuevo estándar de eficiencia energética en la evaluación de la vivienda social. Caso de estudio: Vivienda de Barrio Papa Francisco. *Hábitat Sustentable*, *10*(1), 44 -55. DOI: https://doi.org/10.22320/07190700.2020.10.01.04 HS

Ministerio de Educación (1998). *Criterios y Normativa Básica de Arquitectura Escolar. Dirección de Infraestructura*. Gobierno de la Nación. Argentina.

Pontoriero, D. (2017). *Banco de datos meteorológicos, 2006 a 2015*. Instituto de Energía Eléctrica, Facultad de Ingeniería, Universidad Nacional de San Juan.

Ré, M.G. (2017). Arquitectura escolar. Análisis del Programa Nacional 700 Escuelas en la Provincia de San Juan. *Actas del XXI Congreso ARQUISUR*. Eje 1. Trabajo N°30. En: https://www.researchgate.net/publication/320300087_ARQUITECTURA_ESCOLAR_ANALISIS_DEL_PROGRAMA_NACIONAL_700_ESCUELAS_EN_LA_PROVINCIA_DE_SAN_JUAN

Ré, M.G., Blasco Lucas, I. y Filippín, C. (2016). Evaluación higrotérmica y energética de un edificio escolar perteneciente al Programa Nacional 700 Escuelas, en el Área Metropolitana de San Juan, Argentina. *Hábitat Sustentable*, *6*(2), 40-51.

Rocky Mountain Institute [RMI] (2020). Recuperado de https://rmi.org/

San Juan, G. (2014). *Aprendizaje en las escuelas del siglo XXI. Nota 5. Auditoría ambiental y condiciones de confort en establecimientos escolares*. Banco Interamericano de Desarrollo.

Sekki, T., Andelin, M., Airaksinen, M. y Saari, A. (2016). Consideration of energy consumption, energy costs, and space occupancy in Finnish daycare centres and school buildings. *Energy & Buildings 129*, 199–206. DOI: 10.1016/j.enbuild.2016.08.015

Selectra (2020). Factor de conversión del gas natural, de m^3 a kWh. Recuperado de https://preciogas.com/faq/factor-conversion-gas-natural-kwh.

Trisnawan, D. (2018). Ecotect design simulation on existing building to enhance its energy efficiency. *IOP Conference Series: Earth and Environmental Science*, *105*. DOI:10.1088/1755-1315/105/1/012117

Veloso, A.C.O. y Souza, R.V.G. (2019). *Peso do sistema de arcondicionado no consumo de energía eléctrica em edificacao de escritorios: estudo de caso em Belo Horizonte – Brasil*. International Building Performance Simulation Association. IBPSA.

Wang, S., Yan, C. y Xiao, F. (2012). Quantitative energy performance assessment methods for existing buildings. *Energy & Buildings*, *55*, 873–888.

Wikipedia (2020). Mapa de Argentina con localización de la provincia de San Juan. Recuperado de https://es.wikipedia.org/wiki/Provincia_de_San_Juan_(Argentina).