Development of a retrofitting tool for classrooms

Manuel Alejandro Inostroza Pinares
Universidad del Bío-Bío, Facultad de Arquitectura, Construcción y Diseño, Concepcion, Chile
manuel.inost@gmail.com

Jeremy Michael Piggot Navarrete
Universidad del Bío-Bío, Facultad de Arquitectura, Construcción y Diseño, Concepcion, Chile
jeremy.piggot@gmail.com

María Beatriz Piderit Moreno
Universidad del Bío-Bío, Facultad de Arquitectura, Construcción y Diseño, Concepcion, Chile
mpiderit@ubiobio.cl

ABSTRACT: Several investigations have led to understand how architecture and the environmental surrounding such as natural lighting, thermal performance, and air quality influence on learning processes and are the key to provide comfort for the students. The purpose of this research is to study the application of different energy retrofitting strategies in classrooms of the city of Concepción, Chile. The main objective was to develop a tool for the classification of existing classrooms according to their level of energy efficiency to subsequently provide different strategies to retrofit those classrooms. In the first stage the influence of different architectural elements for the environmental comfort and energy demand was defined, also, the different results of the energy simulation developed in EnergyPlus to a typological classroom where analyzed. Then the modifiable variables where determined in order to select those that influence the energy consumption of the classroom in a more effective manner, such as the orientation, thermal envelop, airtightness, type of glassing and percentage of window surface. Subsequently, retrofitting strategies based on levels of architectural intervention and retrofitting costs where proposed, materials costs were recorded in the market, considering transport and installation of those materials. After that, the costs saving in the energy consumption that the application of each strategy would generate and recovery that their application would generate was determined; as a result, an interactive and easy to use tool was created. In just a couple of steps it is possible to see some alternatives of intervention provided by the tool to retrofit a certain classroom. This provides the user with a tool that compares the current situation of a classroom with a more energy-efficient situation.

Key words *Retrofitting Energy Demand Concepcion Schools Tool*

ISBN: 978-85-92631-00-0

1. INTRODUCTION

Several studies have shown that achieving environmental comfort in classrooms has a positive impact on the well-being and health of the students (Sensharma, Woods & Goodwin, 1998; Bluyssen 2014). Children spend much of their time in the classroom, therefore, we as architects must design schools focused on achieving a high environmental standard, offering the best environmental conditions for their development, and at the same time, reduce the energy demand generated.

In the environmental-energetic context of the schools in Chile, studies have proved that their environmental conditions are poor, with poor thermal conditions and an inadequate quality of the air inside the classrooms (Armijo, Whitman & Casals, 2011; Trebilcock et al., 2012); There is no thermal regulation which ensures basic conditions for environmental comfort in classrooms and there are limited publications related to the design of classrooms applicable to the design of new facilities. (GEEEduc, Trebilcock et al., 2012). The General standard of Construction and Urbanism of Chile establishes that schools located south of latitude 36 ° S, as is the case of Concepcion, must have heating systems; However most of the schools in Concepcion do not use such systems due to budget considerations, which aggravates their thermal conditions, especially in winter. Recent studies which were developed in different cities of Chile to measure the operating temperature and the comfort conditions of students inside the classroom allowed us to conclude that the interior temperature is below the appropriate conditions in the vast majority of classrooms (Trebilcock; Piderit, 2016).

There is a high number of schools that require to be retrofitted to improve their interior conditions and lead to a full learning environment. Within this context this assessment is made with the objective of creating the basis for energy retrofitting, as a support tool for professionals who work on the improvement of environmental conditions in schools. The objective is to progress in the development of sustainable schools in Chile which are characterized by a lower energy consumption and environmental comfort, achieving heat comfort, quality light and air standards.

2. METHODOLOGY

2.1 Retrofitting of school classrooms

It is essential to advance in the retrofitting of schools in a sustainable manner to support energy architectural interventions, focusing on three aspects of the sustainability design: Indoor environment, welfare of the students and economic sustainability.

The main objective is to develop a tool that supports architects or managers of schools when the time comes to decide what to do during the stage of retrofitting. Based on a predefined type of classroom different passive design strategies for energy retrofitting of existing classrooms are incorporated. Energy evaluation results allow us to develop a classification of the energy demand of a typological classroom for Concepcion.

ISBN: 978-85-92631-00-0

According to the value of the energetic demand, the tool offers systematically different retrofitting options, by means of different passive strategies. The initial cost of the intervention and the amount of time required to recover the investment were evaluated for each of them.

This research is carried out in the geographical center of continental Chile, in the city of Concepción, located at 36 ° 47's and 73 ° W at fifteen meters of average altitude above the level of the sea, which is part of the climate area called "South Coast", which is characterized as a costal climate, with frequent rainfall and warm to cool temperatures (Meteorological service Chile, 2012).

2.2 Definition of a typological classroom

The development of the tool is based on a typological classroom of 54 m2 made with reinforced masonry in which various design parameters are modified in order to improve the environmental comfort and reduce its energy demand.

The energy demand simulation results of 4800 dynamic combinations of classrooms performed by the CITEC UBB for the "guide of energy efficiency for schools" are considered in this assessment. These simulations were made in an integrated way considering the heating, cooling and lighting demands at the same time. The optimization software "GenOpt" was used in addition to the "Energy Plus" software for the energy simulation of each of the classrooms using the respective climatic data of Concepcion.

The energy demand simulation outcomes are determined by the orientation of the classroom, the thermal characteristics of its crystals, the percentage of the window panes surface, the thermal envelope type and the hermeticity. The value of the energy demand is determined by how external conditions interact with the building, either in a positive or negative manner. Table 1 shows the different design parameters used for the demand calculation in the typological classroom. (Geeeduc, Citec, Ubb, 2012).

Table 1: Design variables (source: Trebilcock & Piderit, 2016).

Design parameters	**Variable**
Orientation of the classroom	North, South, East, West
Percentage of window panes surface/ Classroom base surface	20% - 23%
Type of glass	Simple - Double - Double (Low emissivity)
Hermeticity - N50 Factor (ach)	0.5 - 1.5 - 2.5
Thermal envelope	A-B-C-D-E

2.3 Energetic evaluation of a classroom in Concepcion

Studying the classroom simulation outcomes, the parameters which have more influence on the energy demand can be defined. In Figure 1 we see that "Hermeticity or air tightness of the envelope" is the most influential parameter and it is related to the presence of hidden cracks which allow air to flow through the envelope of the classroom causing heat loss. Also the orientation of the classroom becomes relevant within the value of its total

ISBN: 978-85-92631-00-0

energy demand since it is the variable that has the most influence in the decrease of the artificial light demand.

In the case of the thermal envelope the influence is also very significant, especially in the cities of the South of the country, in the case of Conception an efficient thermal envelope with a good insulating capacity (low U value) is highly recommendable to keep the heating demand lower than other cases. The type of glass and the percentage of window panes surface do not generate a significant influence in the energy demand of the building, but they can be easily modified to generate some valuable Kwh/m2 when it is desired to make a difference by decreasing the thermal demand. (Geeeduc, Citec, Ubb, 2012).

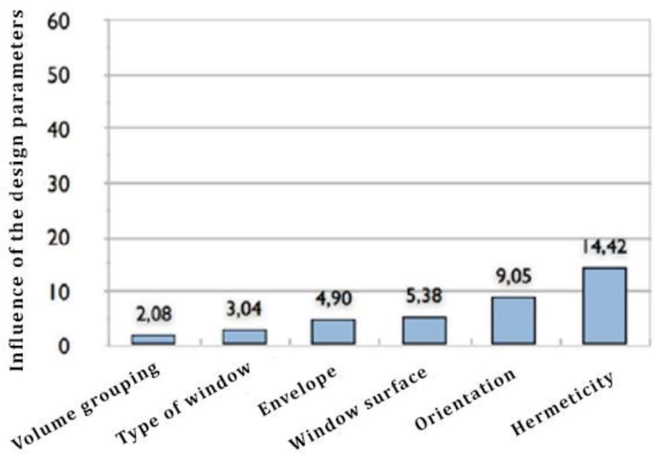

Figure 1: Influence of the design parameters in Concepcion (Source: GEEEduc, UBB Citec)

Regarding the energy demand (Kwh/m2), the evaluations determines that in Concepción, the demand for heating has a 69.6% of influence, the lighting demand is also important haveing 30% of influence on the total demand and the cooling demand has almost 0% of influence because the average temperature never reaches a higher level than the thermal comfort (Geeeduc , Citec, Ubb, 2012)

3. RESULTS

3.1 Retrofitting tool for classrooms

The retrofitting tool for classrooms is developed with the collected information, and as mentioned above, it aims to support the design and implementation of improvements that enable a better use of energy in schools. This tool allows the users to make important decisions related to retrofitting strategies and it also helps to quantify the energy consumption currently generated by the analyzed classroom, furthermore, the tool proposes different improvement strategies that lead to a more efficient use of energy, demonstrating the economic viability of the implementation of the proposed strategies.

Each one of the improvement strategies mentioned in the tool are related to the incorporation of different kinds of materials on the envelope and windows of the analyzed classroom, therefore, the mentioned economic viability considers a comparison between the initial cost of materials including labor of the different construction processes, and the cost savings obtained monthly because of the reduction of the total energy demand.

3.2 Application of the tool

The tool is developed in a PowerPoint (.pptx) file which incorporates all the data obtained and classified in different stages, this allows the user to analyze the retrofitting of a classroom in a systematically and simple manner with a simple and didactic language for a clear understanding; The different tool stages are explained in the following paragraphs.

3.3 Initial diagnosis of the classroom

Initially the tool provides a diagnosis stage where the user must answer some questions in order to be aware of the current situation of the classroom and the characteristics of the case that it is desired to evaluate. At this stage, the user should select the alternatives that reflect the conditions of the analyzed classroom according to the following characteristics: orientation, envelope type, airtightness, window panes surface and the type of glass. It is possible to see some examples of this in Fig. 2

Orientation selection | Envelope selection | Diagnosis result

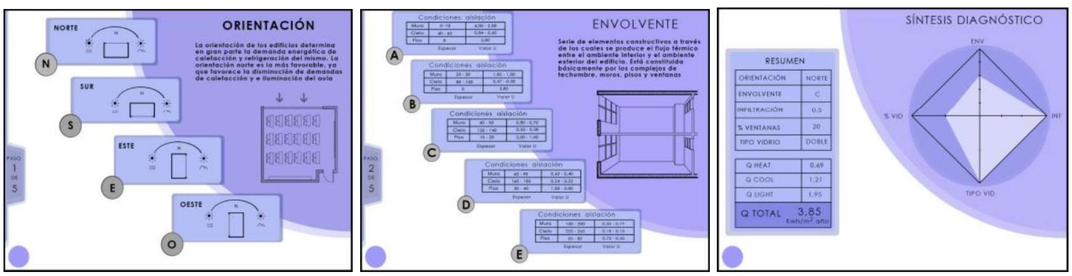

Figure 2. Process of selection of classroom conditions in the diagnosis stage of the tool (Source: Authors)

As the different options are shown, the tool explains each one of them, for example, for the option "choice of type of thermal envelope" 5 options are offered (Envelope A-B-C-D-E), according to a classification of thermal envelopes made by the "UBB Citec" considering the thickness and the position of the thermal insulation in the different constructive elements (table 2). For the walls and floor insulation expanded polystyrene is considered, and for the roof insulation mineral wool is considered.

Table 2: Classification of thermal envelopes (Source: UBB Citec 2012)

Elements	Envelope A		Envelope B		Envelope C		Envelope D		Envelope E	
	Thicknes s mm	U Value W/m²°C	Thickness mm	U Value W/m²°C	Thickness mm	U Value W/m²°C	Thicknes s mm	U Value W/m²°C	Thicknes s mm	U Value W/m²°C
WALL	0-10	4.00-2.00	20-30	1.5-1.00	40-50	60-90	60-90	0.60-0.40	130-200	0.30-0.19
CEILING	40-60	0.84-0.60	80-100	0.47-0.38	120-140	160-180	160-180	0.24-0.22	220-260	0.18-0.15
FLOOR	0	3.80	0	3.80	010-20	2.00-1.50	30-40	1.00-0.80	50-80	0.70-0.45

ISBN: 978-85-92631-00-0

It is essential to be aware of the current conditions of the thermal envelope of the analyzed classroom since, in order to operate efficiently in a city such as Concepcion the classroom should be able to conserve heat and prevent heat losses especially in the coldest periods of the year.

The airtightness as mentioned above, is the most important parameter in Conception, since it strongly influences the energy heating demand. regarding this parameter the tool offers three options of hermeticity (infiltration of air) into the classroom 2.5 ach - 1.5 ach - 0.5 ach (ach: air changes per hour). The value of air changes per hour is used, among the other parameters, for the energy evaluation of classrooms but there is a problem, the airtightness is probably the most difficult parameter to analyze in the classroom since it depends on a great number of factors related to hidden cracks in the enclosure, pressure differentials and temperature differentials between the inner and outer spaces. Therefore the tool questions the user, and according to the answers, it calculates an approximate amount of air renewals within the classroom.

The questions made by the tool are intended to evaluate the presence of cracks or fissures in wall-floor and wall-ceiling joints; the presence of cracks or poor door-frame and window-frame element joints. Table 3 shows the criteria used for the definition of the hermeticity values, a simplification is made to be able to add it to the tool.

Table 3: Criteria utilized for calculation for classroom air infiltration

Criteria	Airtightness (Infiltration, Air changes per hour)
Doors, windows and joints do not present any deterioration that generate air infiltration (	0,5 ach
Joints between walls, ceilings and floors are in good condition, but doors and windows, or both, exhibit damage	1,5 ach
Joints between walls-ceiling, wall-floor, joints of window with glass or wall frames and door joints exhibit damage that generates air infiltration	2,5 ach

The size of the window panes surface of the classroom generates a positive effect on the visual comfort of students and at the same time reduces the need for artificial lighting. In Concepcion the standard requires that the window panes surface must be greater than 20% of the total base area of the classroom. The user must indicate if the percentage of window pane surface of the classroom is 20% or higher for the purposes of the calculation of energy demand.

The type of glass is responsible for approximately 15% of heat loss in the classroom, therefore the user should indicate if the analyzed classroom has simple or double glass, depending on the answer, the tool will take a different U value of the glass to perform the energy calculation.

ISBN: 978-85-92631-00-0

Finally, when all the classroom characteristics are identified in the diagnosis stage, the tool will generate an annual energy demand calculation of the classroom. The next stage, will present different energy retrofitting proposals.

3.4 Proposals for energetic retrofitting strategies

After obtaining the energy demand the tool advances to the phase of energy retrofitting, where it shows the current condition of the classroom (A) and offer 3 different improvement proposals (1, 2 and 3) to some of the current features of the classroom and reduce the energy demand (see Figure 3).

The 1st proposal considers improving the thermal envelope by increasing the thermal insulation in walls, floor and ceiling of the classroom. The 2nd proposal considers improving the thermal envelope and in the airtightness of the classroom, therefore besides the increasing of thermal insulation, the joints between walls, ceiling, floor, windows and doors will be improved to reduce the air infiltration. The 3rd proposal considers the improvement of thermal envelope, airtightness and change the simple glass to a double glass type if the classroom still does not have that type of windows.
Since the tool offers retrofitting proposals, the morphology of the classroom or building will never be modified.

Proposal selection | Information of the proposal | Information of costs

Figure 3. Proposal selection.
(Source: Authors)

3.5 Economic evaluation of the energy saving

Once a proposal is chosen the tool allows the user to be aware of the economic costs that the incorporation of such proposal will entail with the objective of generating an analysis of the monetary value of its incorporation and the time in which the school would recover the investment due to the generated energy savings. The time that it will take for the classroom to recover the investment varies from 7.5 to 15 years depending on the current conditions of the classroom and the chosen improvement proposal, this amount of time should be considered quite acceptable considering that, after that time, all energy savings generated are a monetary gain for the analyzed educational establishment.

When all the proposal information is provided the user can evaluate different intervention strategies and decide which of these to implement in the classroom, always considering

ISBN: 978-85-92631-00-0

the most convenient option based on the initial monetary investment and the energy demand reduction of the classroom.

It is important to mention that using this tool the user may quantify the monetary saving, for example, if the current total energy demand of a classroom is 23 (Kwh / m2 Year) and the considered classroom base surface is 54 m2 the of demand values will be the following: (table 4)

Table 4: Cost of the demand values (Source: Authors)

DEMAND	By m2/ year	By classroom (54 m2)	Monthly by classroom (Year = 10 months use)
	23 Kwh/m2 by year	1242 Kwh/ year	124,2 Kwh / Month
Price (in UF) Approx. Value Kwh = 0.01 UF UF= 39.83 US$ (Approx.)	0.23 UF/ m2 by year	12.42 UF/ year by classroom	**1.24 UF / Month by classroom**

3.6 Costs of proposals considered

In order to inform the correct price of the proposal intervention, different materials information was collected, for every proposals the tool details the material and cost of the incorporation.

For the costs calculation associated to the implementation of envelope improvements the considered materials include sheets of expanded polystyrene of different thicknesses (depending on the type of envelope required) as thermal insulation, a moisture barrier and an exterior coating with fastener elements when the thermal insulation is integrated on the outside of the walls and, glass wool of different thicknesses with their respective moisture barrier are contemplated as roof insulation.

For the costs calculation associated to the implementation of improvements in the hermeticity of the classroom the considered materials include glazing gaskets, weatherstrip for double contact, polyurethane foam, an internal glass bumper seal and felt for the windows. For the doors a wooden frame, neutral silicone, polyurethane elastic seals, a bottom weatherstripping seals and a gasket seal are considered. In the wall joints polyurethane foam, structural neutral silicone, expanded polystyrene cornice and a self-adhesive tape are considered.

Finally for the calculation of costs related to the change of the simple glass window of the classroom to a thermopanel double glazed window with inner airtight chamber and a PVC frame that ensures good hermeticity for the construction are considered.

Within all the calculated costs labor, a margin of material loss and legal documentation are considered, all the above data was obtained from the document "Analysis of Unit Prices" and different construction material manuals, generating a database that is pertinent to the use of the tool.

Once the diagnosis and proposals stages are finalized a summary table is generated with the current monthly expenditure, monthly expenditure of the proposal, monthly savings, and the recovery time of the investment, the table can be downloaded in PDF format.

ISBN: 978-85-92631-00-0

4. CONCLUSIONS

The application of this tool provides viable and quantifiable solutions to actual problems of educational architecture in Chile. Its use is intended to refurbish existing educational spaces by decreasing energy demands and increasing the comfort of students inside the classroom. Additionally it also provides improvements in the design of new educational spaces that enables users to test different alternatives in a certain analyzed classroom unless they are already built, providing information in a simple manner with the objective that users are not limited by lack of knowledge about certain terms or mentioned results, the latter encourages massive knowledge related to energy efficiency and the retrofitting of educational establishments

By means of the correct implementation and use of this tool, not only the energy expenditure related to the educational area would be considerably decreased, but in addition to improving the conditions of classrooms built an increase in the productivity of the students would be generated, which is directly related to the decrease of the interferences generated by the deficiencies of the interior conditions such as infiltrations of air, deficiencies in natural lighting and very high or very low temperatures.

As this tool continues to be developed, its scope will not have limitations because it will be possible to continue to expand the variable spectrum to consider, for example to incorporate information about the type of frame and artificial lighting of the establishment, with the purpose of delivering a more accurate diagnosis and results. In addition, it could expand its area of use, integrating thermal dynamic simulations and climate data of different cities of the country, making it possible for the tool to be applicable not only in Concepcion but also in many other cities.

4. ACKNOWLEDGEMENT

This research is developed with students who are doing the last year of the career at the Architecture School of the University of Bío-Bío and carried out with the support of the Group of research in architecture and sustainable building of the University of Bío-Bío.

ISBN: 978-85-92631-00-0

REFERENCES

BASF The Chemical Company, 2008 *La Eficiencia Energética es la fuente de energía del futuro*, Hanover
CITEC UBB, 2012, *Guía de eficiencia energética en establecimientos educacionales*, Concepción
CITEC UBB, 2012, *Manual de diseño pasivo y eficiencia energética en edificios públicos*, Concepción
CITEC UBB, DECON UC,2014, *Manual de hermeticidad al aire de edificaciones*, Concepción
CNE, Comisión Nacional de Energía, (2010) Santiago
FENERCOM, 2008, *Guía de rehabilitación de edificios de vivienda*, Madrid
IDAE, 2010, *Guía práctica de la energía para la rehabilitación de edificios*, Madrid
Programa Chile sustentable, 2013, *Chile, Energía en Chile ¿Para qué y para quién?,* Santiago
Proyecto Foncedyt 11121608 ILUMINA, 2014, Concepción
www.acee.cl Agencia Chilena de la Eficiencia Energética
www.igdigital.clInformación económica de Chile
www.tutiempo.net Datos climáticos de todas las ciudades de Chile