Proposal of an Energy-Environmental Rating Method for Public Buildings in Chile

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ABSTRACT: To improve the environmental quality, efficiency and savings on energy use in public buildings is nowadays an issue of major importance in Chile. The following investigation shows part of a research project commanded by the Chilean government with this regard. The aim was to evaluate both the energy and the environmental performance of different public buildings, the factors affecting it, and furthermore, to identify and develop opportunities for energy saving. This paper exposes the design and validation of a novel benchmarking method developed to assess the building´s energy and environmental performances. The methodology combines monitoring techniques in order to account the building´s energy consumption and to measure the physical and environmental characteristics of the building´s construction, using dynamic simulation techniques and evaluating the users' perception. The method has been successfully applied in assessing ten buildings in five Chilean regions. The authors propose this method as an effective way of assessing and rating building performances and inferring from those results with respect to the efficacy and profitability of the passive and active strategies utilized in the building design, aiming to improve the energy-environmental performance of public buildings in Chile.
Key words: rating method, public buildings, energy-environmental performance

INTRODUCTION

This investigation is part of an 'Innova Chile Project', number 09 CN14-5706, called 'Evaluation of the design and construction strategies, environmental quality standards and efficiency in energy use in public buildings, through the assessment of existing buildings' commanded by the government of Chile through the Architecture Department of the Ministry of Public Works and developed between 2010 and 2012. The project was carried out by a technological consortium integrated by the following research institutions of the country: Construction Institute (IC), Research Center of Construction Technologies of the Universidad del Bío-Bío (CITEC UBB), Construction Extension Department (DECON) and Direction of Scientific and Technological Research (DICTUC) of the Universidad Católica de Chile, and Direction of Research Development, Structure and Materials Innovation (IDIEM) of the Universidad de Chile.

The problem motivating this initiative was the need of the Chilean society of improving the environmental quality, efficiency and savings in energy use in public buildings. This is an economic and social issue affecting the whole country and its energy stability, its environment, the people's quality of life and their productivity, together with an increasing rise on the national budget. Previous studies have demonstrated that if buildings in Chile would reduce its energy consumption by 1.5% during the 2006-2015 decade, the expected savings would be of US 3,459 million [1]. Only the heat losses that result from poor building thermal insulation represents for the Chilean government an extra cost estimated in US 1,000 million per year [2]. Another losses, which are difficult to assess but not less important, result from the deterioration of people's health and productivity caused by uncomfortable living conditions due to the poor environmental performance of the buildings.

In 2005, the Ministry of Economy, through the National Energy Commission (CNE), launched the 'Energy Efficiency Country Program' (PPEE) aiming to consolidate the efficiency in energy use as an energy source, contributing to the sustainable energy development in Chile. In 2006 the Architecture Department of the Ministry of Public Works began to incorporate energy efficiency and sustainable criteria in public buildings, aiming to design and build thermally efficient buildings with improved environmental standards. The result was an important number of finished and under construction public buildings incorporating passive design strategies and innovative high performance heating and ventilation systems. The target was to improve the heating, acoustic, lighting and air quality performances within the buildings. All of this, however, requested a higher investment, which efficiency and profits had to be evaluated by the Chilean Government.

To answer these interrogatives, in 2010 the Architecture Department of the Ministry of Public Work asked the Construction Institute to carry out a research project leading to assess, during the post-occupancy phase, the energy and environmental performance of ten public buildings, designed with and without energy efficiency criteria, in five different regions of Chile. The purpose was to evaluate and compare different design strategies utilized in buildings within the same region (i.e. similar climate), in order to measure the added value derived by the higher investment carried out by the Chilean Government when thermally and environmentally improving public buildings. An additional aim was to identify and to develop energy saving opportunities to be used in the future design and construction of public buildings.

Consequently, the 'Innova Chile N° 09 CN14-5706' project was commended and developed, where different monitoring systems for evaluating the energy consumption, the physical-constructive parameters and the environmental quality of public buildings in use were utilized. Complementarily, perception surveys were carried out aiming to compare the measured environmental quality (quantitative data) with the user's opinion (qualitative data). All this information was used to assess various energy and environmental performances, so as to understand the factors affecting them and to rate the quality of the strategies implemented. In order to evaluate the different active and passive design strategies incorporated to the buildings, a new method was developed by CITEC UBB (www.citecubb.cl), which is exposed in this paper. This method helps to evaluate the effectiveness and cost-benefits of the chosen strategy, through measurements of the energy and environmental building performances.

THE BUILDING REGULATIONS IN CHILE

The Chilean planning and construction area is ruled by the General Urban and Construction Law and its governing instrument: the General Urban and Construction Standards (OGUC). This is a prescriptive code, with no energy and environmental requirements applying to public buildings, which could be used as reference benchmarks for performance assessments. As a legal and technical instrument, the General Urban and Construction Standards is not enough to guarantee that once buildings are constructed they will offer socially acceptable energy and environmental performances. On the other hand, technical standards in Chile are voluntary and those related to the building's energy and environmental matters are limited. One of the most important standards is the NCh1079.Of2008, which establishes a climate zoning for architectural purposes, dividing the country into nine zones and providing general design recommendations with regards to heating, solar and rain water protection. Other standards cover basic calculation aspects, as well as heating and sound proofing testing methods for building elements. However, there are no national standards setting up environmental or energy requirements, or identifying energy efficiency ratings for public buildings.

Nowadays, the General Urban and Construction Standards (OGUC) do not have the faculty to regulate most of the building performances currently demanded by the society. Regulating building performances mean to establish standards and benchmarks in order to determine if buildings partially or totally comply with the requirements. It is necessary, for instance, to set up requirements and limiting values for aspects such as the energy demand of public buildings. This lack of performance requirements restricts the opportunities to develop energy and environmental certification methods for public buildings in Chile.

The starting point of any energy and environmental improvement process is to establish requirements, indicators, benchmarks and compliance verification methods. It is a priority nowadays in Chile to establish standards to regulate important design features of public buildings, such as insulation and air tightness. The actual tendency is to develop design guidelines and construction regulating tools based on performance requirements, which are compulsory when included in the design and building execution contract. In this way, the difficulties and delays entailed in modifying the building regulations with that regard are avoided.

DESIGN AND ELABORATION OF A RATING METHOD

Within this context, the idea of developing a methodology for assessing design strategies incorporated to public buildings was proposed. The method would be based on the assessment and qualification of building performances, which are defined as a set of building qualitative or quantitative features, objectively identifiable, which help to determine the building's ability to respond to the different functions for which it has been designed [3]. The worldwide state of the art related to energy and environmental performance qualification systems and controlling methods was reviewed. Next, considering the technical capacity and the existent support within the country for the assessment of inhabited building performances, it was decided to elaborate a 'benchmarking' [4] rating method, which would compare the measured building performance with good, acceptable and poor performance references. These references (benchmarks) would be observed for the same climate, technology, economic opportunities and social expectation aspects. The method herein developed includes the following items:

a) Performance requirements
b) Indicators or measurement means for assessing the buildings' performance
c) Type of performance
d) Performance criteria expressed in limiting or acceptable values
e) Performance measurement techniques and protocols

The method established seven performance levels: A (excellent), B (very good), C (good), D (moderately good), E (acceptable), F (poor) and G (very poor), in a similar way as the labeling system for qualifying electric appliances. The scope of the range between the levels A and G was defined for each performance, based on the analysis of the local state of the art and from a technical and economic feasibility analysis. The intermediate level E represents the acceptable class and it is defined from the requirements and benchmarks established in the national standards and building regulations when available, or from local studies, foreign regulations or established agreements, according to the existing expectations.

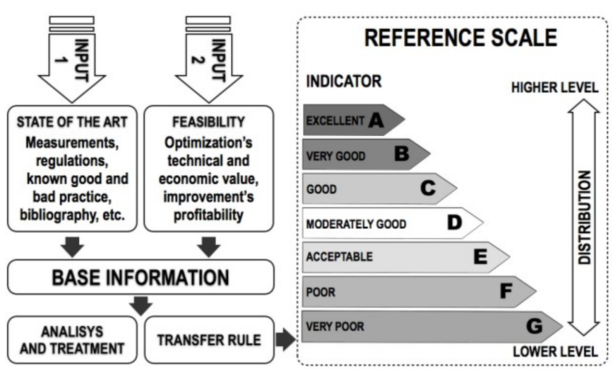

Figure 1: Structure of the performance rating method.

The performances considered by the rating method were nine: three aiming to qualify the building design, four intended to rate the indoor environmental conditions, and two designed to qualify the performance of the lighting and space conditioning systems. The Figure 1 shows the structure of the developed model applied to each of the performances considered in the system, with their main components.

Requirements and indicators

The requirements are defined as a function of the users and the society interests. They are related to the specific conditions which have to be verified in the building design, its systems and its components, in order to meet a previously defined performance or objective. The indicators, on the other hand, are means or concepts used to assess performances and to verify the way in which the objective is accomplished, by comparing the results with the quality references defined by the rating system. The requirements, indicators and metrics considered in this method are defined as follows:

- Energy efficiency: related to the building's design features and their ability to appropriately limit the energy demand for achieving thermal comfort, depending on the local climate, the use of the building and its seasonal regime, together with the building insulation, inertia, air permeability and exposure to solar radiation. Here, the indicator is defined in terms of annual energy demand per unit area of the building, both for heating and cooling. The objective here is to evaluate the ability of the building for limiting the heating and cooling energy demand. The evaluation is carried out by verifying if the building's characteristic thermal parameters comply with the established limiting values and by comparing the energy demand of the building with a reference building. The limiting values considered for the heat transmission through the opaque and transparent envelope elements for each of the climate zones in which the country is divided were those recommended by the NCh1079.Of2008 standard. In addition, limiting values for the modified solar factor of the openings were set, according to the percentage of openings for each climate zone, which were taken from European Technical Codes and weather assimilation [3]. The limiting values for air permeability were taken from a local research which is currently in progress. With regards to the reference building, it was defined as a building having the same shape, size, internal zoning and use as that on the actual building. It has also building elements and façade component, floors, roofs and shading devices with matching qualities with the characteristic limiting values of the climate zone in which is located. The energy demand in the reference building should be higher, either in the heating or in the cooling period, than the evaluated building in order to consider its design as suitable in terms of energy use.
- Acoustic insulation: Aiming that the building design includes acoustic insulation properties able to limit the

airborne and impact sound, a proper airborne sound insulation of the façade and other features allowing guaranteeing the acoustic comfort of the occupants. The indicators for these requirements are defined from the sound reduction indexes of the façade elements as well as the partitions within the building.

- Natural light contribution: Regarding that the building design has characteristics for optimizing the daylight contribution to favor the development of activities, the visual comfort and energy savings in the use of artificial light depending on the local climate, the location and the use of the building, its spatial design, its geometry ant the reflectivity of their surfaces. This requirement is measured by daylight contribution indexes defined from recommended reference values.

- Hygrothermal comfort: Aspiring that the building design and its thermal conditioning systems would have the needed features to ensure the hygrothermal comfort of the occupants depending on the local climate. This requirement is measured by the percentage of the occupation period where both the temperature and relative air humidity of the space are within the comfort zone, determined by the SET Index and the Auliciens equation [5], considering air velocities, clothing and activities that are normal within classrooms.

- Acoustic comfort: Aiming that the building design and the noise sources within it have such characteristics that the sound environment is acoustically comfortable for the users, according to the space type and the activities carried out on it. The requirement is assessed according to the environmental noise levels, reverberation time or speech transmission index.

- Lighting comfort: Regarding that the building design and its artificial lighting systems have features to satisfy the visual comfort needs according to the developed activities on each space. The requirement is assessed by indexes which weigh up parameters of quantity, quality and light distribution within the spaces.

- Respiratory comfort: Related to the means to be provided within the building in order to properly ventilate the spaces, eliminating the pollutants arising during the normal use of the building, supplying enough outdoor air flow to ensure the extraction and expulsion of the stale air. The requirement is assessed based on the percentage of the occupancy time of the space where the CO_2 concentrations are below 1000ppm.

- Efficient heating systems: Aiming that the thermal conditioning systems specified for the building have characteristics to properly limit the energy consumption needed to for achieving thermal comfort, depending on the local climate, the design and the use of the building in the summer and winter periods. In this case the efficiency is assessed by determining the energy demand and the energy consumption of the building, establishing a ratio between both values.

- Efficient lighting systems: Aiming that the artificial lighting system specified for the building have characteristics to properly limit the energy consumption necessary for meeting the needs for visual comfort, depending on the building design and its use. Efficiency is assessed in this case by determining the power consumption required to meet a standard lighting level.

Assessment Techniques and Analysis

The on-site compilation of information considered continuous and/or punctual measurements of a series of physical-constructive, environmental and energy consumption parameters. The identification of the indicators and the performance assessment combined experimental monitoring techniques with simulations. The monitoring techniques were used in order to assess energy consumptions under dynamic regime, evaluating the hourly, daily and seasonal consumption patterns, together with assessing environmental variables and thermal, acoustic and leakage construction properties. It worth mentioning the use of thermal-flux measurement techniques, pressurization and thermography, which up to that time were never combined for assessing public buildings in Chile. In parallel, surveys were conducted in order to evaluate the consistency between the user perception and the environmental variables assessed.

The elaboration of the rating method considered the design of standardized assessment protocols and information gathering, as well as the training of technical staff. The process also included a stage for testing and validating the protocols, which was undertaken at the Research Center of Construction Technologies (CITEC) of the Universidad del Bío-Bío. The building's energy performance was assessed by combining simulation techniques and physical building parameters measured on site, specifically the thermal insulation and envelope's air permeability. The environmental comfort conditions were evaluated by collecting data in a continuous way for a 20 day period both, in summer and winter. In these cases, indoor and outdoor air temperature and humidity were measured, as well as lighting levels, noise and CO_2 concentration. Additionally, a virtual data base was implemented in order to capture, store and convey information via web through a conventional browser, from anywhere with internet access. The system allowed visualizing and remotely controlling the information gathering process. The dimensions, synthesis parameters and utilized techniques and references are summarized in Table 1.

Table 1: Demands, performances, indicators and measurement techniques

Demand / Performance	Indicator	Techniques / Sources
Energy Efficiency	Heating Energy demand Dec, kWh/m² year Cooling Energy demand Der, kWh/m² year Heating system performance R, % Lighting energy consumption Cei, W/ m²Lux	ASTM 518-10 Termal-flux measurement to determine the envelope thermal transmittance Pressurization according UNE13728: 2003 (Blower Door) for determining air permeability of the envelope Dynamic computer simulation using TAS Monitoring of energy consumption variables as thermal and lighting protocols
Acoustic Insulation	Sound transmission loss in facades D2m nT, dA Sound transmission loss in dividing elements R', dBA	ISO140-5: 1998 Standards to determine differences in standard levels on site NCh 2785.Of2003 standards to determine apparent sound reduction on site
Daylight Contribution	Daylight factor FLD, %	Dynamic computer simulation using Radiance. Monitoring of lighting variables according to measurement protocol
Acoustic Comfort	Environmental noise LAeq,T , dBA Reverberation time Tr, s Speech transmission index STI, s/d	ISO1996-2:2007 Standards establishing environmental noise on site. ISO3382:1997 Standards establishing reverberation time on site
Lighting Comfort	Percentage of time with acceptable illuminance PtI, % Percentage of time with acceptable illuminance distribution PtDI, %	Dynamic computer simulation using Radiance. Monitoring of lighting variables according to measurement protocol
Hygrothermal Comfort	Percentage of time within the comfort zone PCH , %	Monitoring of temperature and relative air humidity variables according to measurement protocol
Respiratory Comfort	Percentage of time with CO_2 concentration under 1000ppm, PCO2 , %	Monitoring of CO_2 concentrations according to measurement protocol

APPLYING AND VALIDATING THE RATING METHOD

The method herein developed was utilized for conducting the energy and environmental qualification of the ten buildings needed to be assessed by the research project. Following, part of the results of one of the evaluated buildings is shown. It is an educational building located in the IX region of Chile, called Francisco Valdes Subercaseaux School. What is here exposed is a summary of some of the environmental performances assessed within the classroom N°5. This space is a brick masonry construction, with its main façade facing northeast. The U-value of the walls is 0.75 W/m² ºC, the classroom floor area is 45 m², its volume 112 m^3 and its occupational density 0.75 students per square meter.

Energy performance assessment

The assessed building has a heating demand of 40.4 kWh/m^2 year, which is 3% lower than the value calculated for the reference building in that location. Hence, the building's energy performance for heating was rated as level E (acceptable). On the other hand, the building's cooling demand is lower that the reference value, being that performance rated as level D (moderately good) (See Table 2 and Figure 2). According to the results obtained by using the proposed rating method, the building has a suitable design for satisfying its heating demands.

Table 2: Summary of the assessed building energy performance and the reference building

Measurement Parameter	Unit	Assessed building	Reference building
Heating energy demand	kWh / m^2 year	40.4	41.7
Cooling energy demand	kWh / m^2 year	5.6	6.3

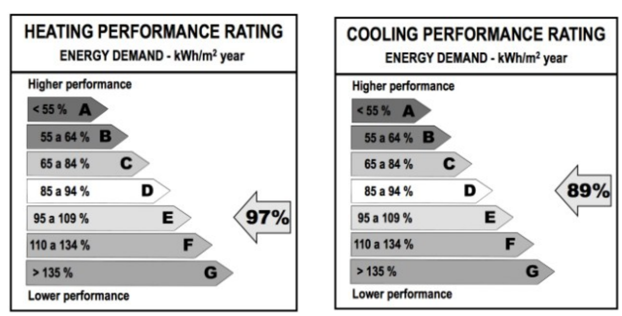

Figure 2: Building design energy rating according to the heating and cooling energy demand.

Hygrothermal comfort assessment

68% of the air temperature and humidity readings carried out during occupancy time in the classroom were within the defined comfort zone. Therefore, the classroom's hygrothermal comfort was rated as level D (moderately good). The method assumes that level E (acceptable) is achieved when at least 50% of the measurements are within the comfort zone (See Table 3 and Figure 3).

Table 3: Summary of the hygrothermal comfort performance in winter time within the classroom N°5 (C5)

Space	Number of readings during occupancy time	Number of readings within the comfort zone	Percentage of readings within the comfort zone (%)	Minimum temperature during occupancy time (°C)	Maximum temperature during occupancy time (°C)
C5	85	58	68	11.3	20.2

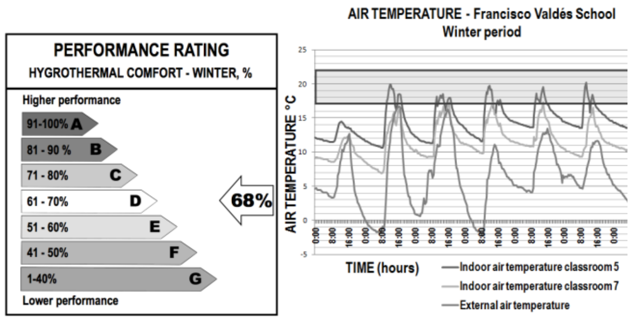

Figure 3: Hygrothermic comfort assessment and temperature variation during the winter period within the classroom 5.

Respiratory comfort assessment

During winter time, the building's means of ventilation were found to be insufficient for providing an acceptable indoor air quality within the classroom N°5. Only by 19% of the occupancy time the indoor air CO2 levels were below the benchmark of 1000ppm. The method assumes that level E (acceptable) is achieved when this period is above 60%. Therefore, the respiratory comfort within the classroom N°5 was rated as level G (very poor) (See Table 4 and Figure 4).

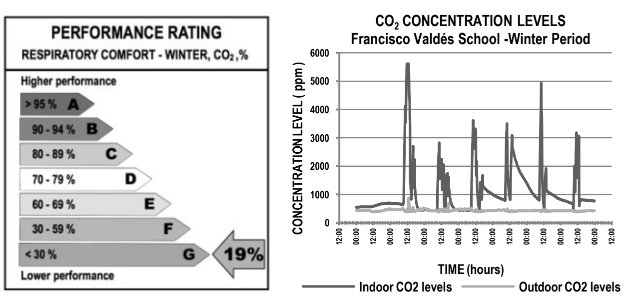

Figure 4: Assessment of the air quality and CO2 concentration variation within classroom N°5 during winter time.

CONCLUSION

In the current state of development and application of the exposed energy-environmental rating method, the following comments and conclusions can be drawn:

The use of the rating method allows measuring and discriminating different building performance levels, and it has been useful in deducting the benefits related to the increased investment made by the Chilean government for improving the energy and environmental performances of the evaluated buildings.

There is nowadays on the market a wide offer to acquire sensors and instruments for commercial equipment, feasible to be used for implementing sensorial nets and monitoring systems in order to measure building performances. Major difficulties arise when there are no requirements and performance criteria. The international requirements and benchmarks can be used as a reference point, but properly adjusting them to the economic, technological and social conditions of each country.

The method defines requirements and minimum acceptable values for various topics not yet regulated in Chile. The minimum values in these cases are based on the international state of the art review and on the few available experimental studies carried out locally. The work being currently developed is focused on refining the requirement levels and their limiting values, as well as incorporating new building performances to be added to the assessment method.

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