A roadmap for net zero energy schools in Chile

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Abstract. During the last ten years, there has been an increasing development of the Net Zero Energy Building in industrial countries. For example, the European Union mandates that by 2020 all new public buildings must comply with the European Directive for nearly Zero Energy Buildings. In the context, of knowledge transfer and investigation of the implementation potential of high-performance building in Chile, this paper presents the findings of a comparative study that was done considering the Belgian regulation landscape. The study focuses on school buildings and the challenge of sustainable building design, construction and operation. The aim of this research is to present a roadmap to Chilean policy makers and designers to progressively understand and implement the Net Zero Energy Schools concept in all new constructions. The research methodology followed a mixed approach combing a literature review of the performance standards, case study comparison, and focus group discussions with Belgian and Chilean experts. The results of the comparative analysis indicate the need to set out a low-tech concept for Net Zero Energy Schools. The focus group discussions resulted in the validation of a novel roadmap and the identification of the most important performance aspects to consider for its implementation. Finally, the paper provides valuable guidelines and technical recommendations besides a roadmap that can be used for strategical planning to implement Net Zero Energy Schools in Chile.

1. Introduction

The growing adoption of the Net Zero Energy Building concept, and the general knowledge of its benefits, has led to an evaluation of the convenience of incorporating this concept into the building codes in industrialized and developing countries [1]. The European Union, for example, has set out goals for 2020 making the member countries incorporate this concept into their construction codes [2]. However, this concepts is not widely adopted across Europe due to financial, social and technical barriers [3]. For example, in Southern and Eastern Europe there is a lack of a strong technological and human infrastructure to guide the adoption and implementation NZEB projects [4-5]. Like the Eastern and Southern European context, Chile is a developing country with limited human and industrial infrastructure. In the same time, Chile signed the Paris Agreement in 2016 and looking forward to preparing its built environment to become energy and carbon neutral. Therefore, this study investigates the design measures and technical requirements needed to reach the ne-zero energy performance goals in schools.

2. Methodology

In this section, we present the research methodology, including the study conceptual framework. Like the work of Piderit et al. [6], our research methodology combines a literature review and focus groups discussions (FGDs). The concept of this study was built around three axes in the context of developing a road for net Zero Energy Schools (NZES). This research borrowed from the review continuum presented by Vivanco in 2017 [7]. The study approach focused on three key approaches for data collection and validation of the proposed framework. Figure 1, illustrates a detailed flow chart of the research endeavor.

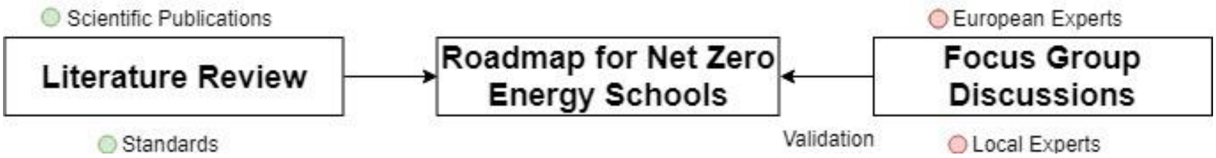

Figure 1: Study conceptual framework to create and validate the roadmap for net zero energy schools

The first axe of our research methodology was based on a detailed literature review of an extensive number of publications. The literature review was prepared by exploring resources that refer to the concept and to building energy policies. The publications included standards, technical codes, books, manuals, conference materials and scientific magazine articles. For the first level of research we checked topics regarding the definitions of the NZES concept. This provided a panorama of advances and evolutions of the NZES concept. The second stage of research involved the classification and screening of the literature review findings in order to translate them into a framework. The KPI's of NZES were identified through the detailed study of the publications. Then, we started to articulate and define the major components and requirements of a potential Chilean standard. For validation, a qualitative method, namely Focus Group Discussions (FGD), took place with more than 60 building professionals. This allowed getting to test our framework and the potential market uptake of NZES in Chile. FGD discussion took place on the 27th of July in 2017 in the auditorium of Timber Engineering Faculty of the Bio-Bio University in Conception, Chile [6, 8]. The FGDs were organized around five round-table groups, guided by a facilitator to assess the roadmap regarding: 1) Technological Approach; 2) Energy Efficiency Requirements and Primary Energy; 3) Indoor Environmental Quality Requirements; 4) Renewables Share; and 5) Construction Quality.

The results were then discussed, allowing for the identification of future milestones. The discussions helped to contextualize the roadmap within 2030, 2040 and 2050 target scenarios. Also, the FGDs identified the challenges to make NZES a mainstream in the construction sector and to align with the energy policies included in ENERGIA 2050 Strategy [9]. Validated FGDs were analyzed by research theme to identify and understand the reality of NZES performance requirements, added value and potential for scaling up.

3. Current situation of public schools in Chile

3.1. Developments towards the integration of the net zero concept in schools

Several analyses and initiatives have taken place internationally regarding the implementation of the NZEB concept in schools. In Northern Europe, several projects have been implemented to incorporate the net zero concept. In Belgium, the "PassivScholen" project was promoted in 2012 by the government of the Flemish region to build new nearly-zero energy schools [10]. This project comprised the construction of more than 30 educational buildings in compliance with the Belgian PassivHaus standard and the nearly-zero energy building objectives. The main aim of this project was to build up a Belgian expertise and provide learned lessons to be applied in the future construction of schools [11]. The most important learned lessons from this project were: 1) The high occupation density per metered squared in classroom and its implication on energy use intensity and energy neutrality, 2) the importance of high insulation and airtightness to reduce the heat losses, 3) the failure to estimate the impact of high internal heat gains and solar gains on overheating; and 4) the challenging nature of NZES that makes it difficult to maintain good air quality, control noise and avoid overheating and in the same time keep the energy use intensity low [11-15].

In same time, in Chile, the main problems in schools are also related to fuel poverty, cost, air quality and thermal comfort [7, 16-17]. However, this type of problems tends to be critical and often Chilean schools fail to achieve acceptable comfort and air quality levels. The study led by Trebilcock et al. in 2017 [17], proofed the poor quality of the indoor environment inside classrooms, where some of the schools assessed had minimum temperatures of 8°C in winter. The main findings were showing the holistic and multi-criteria focus of the concept, the strength of prioritizing comfort and IAQ to determine the energy efficiency levels and the provision of renewable energy, and the suitability of the concept to improve resiliency when facing disasters.

In conclusion, the focus for the construction of new ultra-efficient school buildings should not be mainly focused on energy efficiency or energy neutrality, but mainly on high indoor environmental quality.

3.2. Environmental comfort standards and design guidelines

There is an important difference between energy and environmental performance targets set by industrial and non-industrial countries. Historically, energy efficiency standards have been developed since longer time in Europe, Japan and North America. The comfort models were mainly based on static models [1]. Thus, building standards in industrial countries respond to their socio-economic development, following comprehensive approaches based on performance and compulsory certifications that allow verifying the compliance of the standards [19]. Therefore, Chile should rely on locally developed adaptive comfort models that correspond to the socio-economic context. The emerging new models for thermal comfort models in residential building can be a good start to develop genuine adaptive comfort models [20]. Such models should follow multi-criteria approaches involving air quality, acoustic beside classical thermal comfort parameters.

3.3. Performance indicators in schools

There is an interest in improving environmental quality within educational establishments in Chile. The Ministry of Education has invested in the evaluation of performance and the renewal of regulations to ensure environmental quality in schools in the country. However, the measurements do not consider all the factors and parameters necessary to evaluate the interior quality. At the international level, there is no consensus on the methods, indicators and equipment to be used for the evaluation of the internal environmental quality (IEQ) in schools.

4. Results

4.1. School Performance Requirements

4.1.1. Performance requirements

The strength of having a target is that it helps design teams to reach a measurable ultra-efficient target. In Europe, there is a discussion on Energy Use Intensity (EUI) thresholds to be 15 or 20, or even 40 kWh/m2/y. What is more important in Chile is to set a performance target limit. In the same time, there is a need to set prescriptive performance targets for different design parameters for the building geometry, envelope, loads, HVAC systems and RES systems. Table 1, presents the outcomes of the focus group discussion for two NZES scenarios.

Table 1: Comparison between the high-tech and low-tech approach for NZES.

	High-Tech Approach	**Low-Tech Approach**
EE Target	15 kWh/m^{2}y	30 kWh/m^{2}y
RES Target	15 kWh/m^{2}y	15 kWh/m^{2}y
Envelope	Max. Insulation and air tightness	Max. Bioclimatic design
Thermal	Static and adaptive models	Adaptive models
Air quality	1200 ppm	1000 ppm
Behavior	Unconscious and rigid	Conscious and Adaptive
Systems	Mechanical ventilation D, efficient	Mechanical ventilation ABC, efficient
Controls	Building Management System	None or limited
Operation	Full time expert	Basic

4.1.2. Comfort and Air quality

Comfort and air quality are the most crucial factors in NZES. They come above cost, carbon neutrality and energy efficiency. Comfort is a subjective indoor environmental quality measure. Between the perception-based and evidence-based assessment of comfort, we can find a series of comfort models in literature. These vary from Givoni's model to the ISO 7703 model [40]. For example, the Passive House standard is based on high comfort expectations. But experience shows that comfort strongly relates to the socio-economic status of a country. This makes the identification of comfort requirements relevant and dependent on the countries socio-economic status.

4.1.3. Envelope and passive design

NZEB requires that we change the rules of thumb and design assumptions of passive and bio-climatic architecture. NZES requires optimal-sized window-to-wall ratio and shading protection for South facades (in Northern Hemisphere countries), and optimal-sized window openings in North facades for maximum daylighting. This includes understanding a basic principle of passive design that brings insulation and airtightness together.

4.1.4. HVAC + RES

Mechanical ventilation with heat recovery is essential in any NZEB. They require an air distribution network with supply and exhaust tubes. Sizing the air distribution network and integrating these at the floor height can have a significant spatial and financial consequence. The best way to achieve the targeted thermal comfort and respect the air quality requirements is to separate heating and cooling from ventilation. Lessons learned from heating generation systems, recommend the use of gas boilers for small and individual buildings and pellet or log stoves or heat pumps for large buildings or groups of buildings.

4.1.5. Controls and occupants

There are two main approaches to empower occupants and provide an optimal control of NZEBs. The first approach is minimalistic almost seeking manual control of HVAC systems, allowing users to engage with and regulate their own environment. NZEBs are high-tech based facilities that depend significantly on their operator. According to Figure 2, we advise using manual NZEB controls in NZEBs for buildings without skilled management staff. In this case, the use of familiar comfort controls that can be easily operated following a shallow learning curve is recommended. On the other hand, for NZEBs that can be operated by building professionals or facility managers, smart and automated controls are recommended. With time, NZEBs will get more and more connected with the internet of things (IoT). Design teams must make sure that there are full time facility managers or the equivalent for those types of buildings. Finally, we think that both approaches are good, but they depend greatly on the users and the facility management's capabilities and availability.

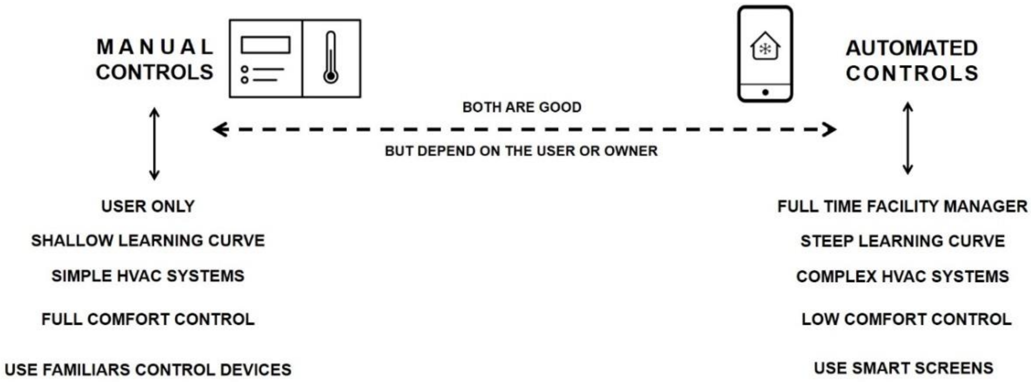

Figure 2: Is a comparison between Manual and Automated controls for NZES

1.1. Towards a Low-Tech approach

Energy transition and resource efficiency that are important in industrialized countries are just as important in developing countries. However, the way of reaching those goals is completely different in industrialized countries and in developing countries. Industrial countries have addressed energy efficiency and renewable energy after meeting housing needs and achieving sufficient comfort conditions in their built environment. On the other hand, most developing countries are looking to close the housing gap and are slowly addressing comfort and indoor air quality issues. In this context, importing the NZEB concept as characterized in industrial countries is challenging. Based on discussions that took place during different focus group meetings we could identify two approaches to achieve NZESs. The first approach is a low-tech approach and the second is a high-tech approach. In the meantime, Chile has to focus on developing low-tech net zero energy schools.

4.2. Roadmaps for NZES implementation

In this section, the roadmap for the implementation of Net Zero Energy Schools (NZES) is presented (see Figure 3). This is the result of the discussion groups and interviews made with professionals and academics with experience in the construction and research of Zero Energy buildings around the world. It addresses the implementation of the concept in 3 stages: short, mid and long term.

5. Discussion

We believe that the roadmap must be implemented in strong coordination with the different sectors that are important for this development, such as: research institutions, government, industry and local experts. Assessing the capacities of each sector will allow defining goals and feasible timeframes

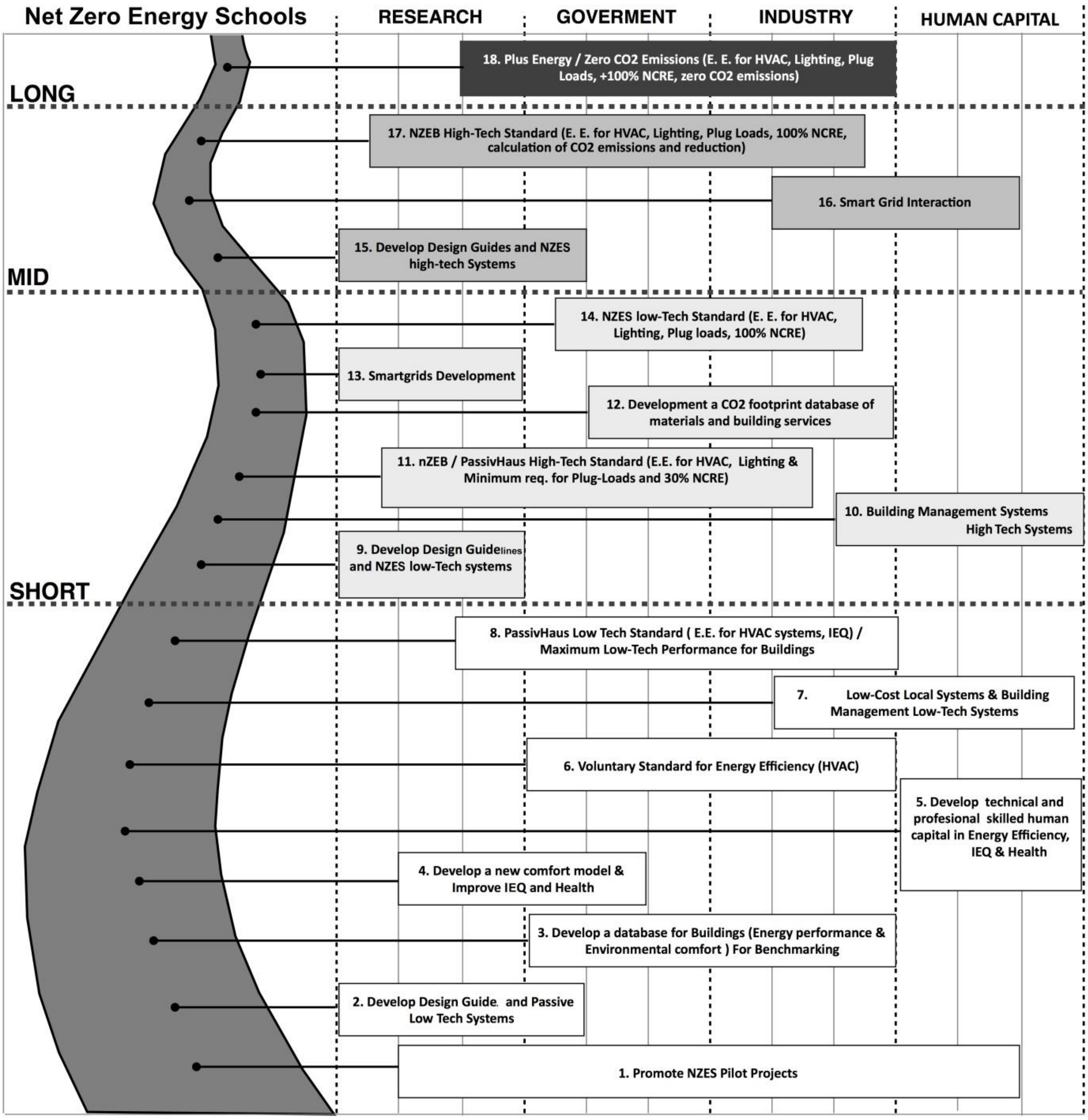

Figure 3, Roadmap for the implementation of a low-tech NZES concept in developing countries

following the development status of each sector. Relying on a collaborative development approaches and elimination of operational barriers, it is possible to speed up the adaptation processes of the NZES roadmap. This multi-sectorial collaboration can avoid the slow uptake of NZES that happened in Eastern and Southern European countries, where the industry and the human capital were not ready to adopt the Energy Performance of Buildings Directive (EPBD) [3]. The lessons learned from Belgium, indicate the need of eliminating operational barriers and promote a joint development and application of the initiatives [16]. In our roadmap, we consider that most of the milestones must be developed in collaboration with at least two sectors and those relevant milestones must be developed by all the players.

The need to carry out pilot projects is the first milestone to implement the suggested milestone and is key to evaluating the state-of-play. The implementation of these projects must allow identifying the cost-optimal NZES, the existing and missing status of the regulations regarding the NZES concept, the capacity of the industry in terms of industrial infrastructure and the provision of implementation, the capacity of the human capital and the expected budget needed to develop these projects [4].

On the mid-term, the roadmap implementation can be based on reaching a low-tech NZES standard, considering that adaptive comfort models and acceptable air quality conditions can be adopted in the short term. A low-tech NZES standard can prioritize the zero balance of the heating/cooling, ventilation and lighting loads for a period of one year with low energy use intensity. On the long term, it is reasonable to consider that the local industry and advanced technology will allow achieving high-tech zero energy schools with higher classes of comfort and indoor environmental quality.

It is important to highlight that the low-tech NZES concept is a good alternative for Chile, which aim at consciously implement zero-energy school buildings. This approach can lead to significant savings through the entire life cycle, making an NZEB policy feasible and increase awareness regarding the long term national 2050 carbon reduction goals. Future research should use the low-tech NZEB concept in more detail to develop prototypes, adaptive thermal comfort models and new multi-criteria IEQ indicators.

6. Conclusion

The purpose of this research was to investigate the potential of implementing the net zero concepts to improve energy efficiency and indoor environmental quality (IEQ) of educational buildings in Chile. The study was completed by investigating the regulation landscape in Belgium and Europe through the discussion with experts from the industrial, governmental and research sectors. Through the discussions that took place in the focus groups and seminars with professionals from the design and sustainable construction sector, the following conclusions were reached:

- Low-tech approaches, can lead to create affordable NZES, based on different cost-optimality scenarios.
- IEQ and thermal comfort in particular are key variables to consider in NZES. Comfort temperatures and good air quality must be guaranteed to reduce the risk of absenteeism and health problems among students.
- Full advantage should be taken from bioclimatic and passive design principles and strategies in the design of NZES.
- Regarding the roadmap, it is necessary to have a common and integrated view, defining objectives that are relevant for the country's development.

Finally, it must be stated that the low-tech net zero concept is highly adaptable to the different socio-economic realities of Chile. Serious efforts are needed to create cost-optimal prototypes of NZES in different climatic regions of Chile. This should be achieved in association with an assessment of the industrial and human capacity in Chile to manufacture, design, construction and operate NZES. Also, context-specific indicators for IEQ assessment should be developed to assure the quality of future schools.

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