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Energy and Indoor Environmental Quality of Residential Construction in Chile.

Analysis of the trends, achievements and pending challenges.

Thèse présentée en vue de l'obtention du

Doctorat en Sciences de l'Ingénieur par

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DEDICATION

... to my parents: María and Luis, for their example always,

... to the future; my children: Aldo, Silvana and Verónica.

ABSTRACT

Energy and environmental quality in residential construction is a matter that concerns and divides Chilean society. At the time that policies and technical aspects are being discussed related to the convenience and opportunity to modify the thermal insulation standards, introduce other standards and, in general, update the thermal regulations for housing, it seemed opportune to carry out this work in Chile. This work helps to develop criteria, judgement criteria and give scientific support for important strategic decisions that the country should make in the short term. It also provides guidance on outstanding tasks and challenges on the topic of the energy performance of the housing stock in Chile.

The progress of the work was structured, furthermore, to meet two very different objectives:

The first objective, which is directly related to the country's need noted above, is met by performing a critical analysis of the trends, achievements and remaining challenges in energy and environmental quality in relation to the indoor climate of buildings intended for housing in Chile. This work is reported in the various chapters of this report. It includes: a diagnostic of the energy quality of building stock, which investigated, for the first time, the energy quality baseline of the housing stock in the country's 54 provincial capitals; a historical review of the evolution of the work done in Chile from 1981 to 2012, in the field of research, technological development, regulations and standards, and building physics laboratory infrastructure, in order to find answers to the energy quality baseline and its gaps in quality by province; and the design of a strategic development plan 2015-2025, which was built based on the experience reviewed and this author's experience, which define objectives, goals, measurable indicators and a total of 76

prioritized actions to reduce gaps and improve the energy quality of the stock, all within a period of 10 years.

The thesis's second objective was to present for third-party judgement, the contribution of this author to the development of building physics in Chile in the past 25 years and, through the promotion of this science, to innovation and technological development in the area. To this end, the process of historical review of the work carried out in the country is made the most of.

An extract of the main conclusions and recommendations of this work are the following:

The energy quality of mass housing construction in Chile is deficient; the stock as a whole demand twice as much energy for heating than that which is strictly necessary. The quality gaps by province are high and very heterogeneous. Quality levels and gaps are compatible with low standards of thermal insulation, a reduced capability of the stock to limit air leakages, the existence of thermal regulations that do not help to limit the demand for energy, and the use of materials, thermal protection and designs improperly adjusted to the nation's climate characteristics.

The work carried out in the last three decades in the area of research and technological development is considered to be moderate. Its volume is limited and its effectiveness, measured by the placement of results on the market according to international standards, is low. While the capability to investigate in Chile has grown considerably in the last decade, there is not yet sufficient critical mass to meet all the research needs with the urgency that lowering the quality gaps demands. The country should increase the volume and quality of research work in all areas and transversely incorporate sustainability concepts and criteria to improve social appreciation.

The regulatory framework, made up of regulations, standards and accreditation systems, is insufficient. The regulatory standards are low, there are areas without regulations and standard support is minimal. Their development has been seriously affected by at least three main causes: the lack of technical laboratory support to verify required performances; the lack of human resources prepared to meet the needs for testing and auditing new requirements; and the traditional resistance from the industry to incorporating changes that mean increasing energy quality requirements. In the country's current state of development, and observing international practice, it is urgent that regulations be incorporated in the areas of hygrothermia, air quality, ventilation, air and water permeability, the energy performance of buildings and others.

The infrastructure in building physics laboratories is created to meet important social demands. In the mid 80's, the first facilities emerge, mainly to support training processes. Then, in the decade of the 90's, other facilities are added to meet the needs for: scientific and experimental support in studies of pathologies under the quality construction law (1996); thermal testing of materials and building components, arising from the requirements of thermal regulations (2000 and 2007); and testing and analysis in the context of processes of research, and development and/or adaptation of new materials, components and building systems. The largest and most modern facilities are concentrated in four centers in Chile; this is a weakness of the laboratory support in the area, considering the country's geographical features. In this field, the main challenges are to create new laboratories and/or strengthen existing ones, in order to assist with the creation of a national quality accreditation system that covers the entire country.

The proposed strategic development plan to improve the quality of the building stock recommends that the country first create appropriate

conditions to generate development. The first condition is to implement a modern regulatory framework with a performance-based approach. In this process, the State must have a much more active role in safeguarding the general interests of society and research centers in the development of knowledge. The work in science and applied research must have high priority in order to develop information and criteria to define standards, carry out economic and social studies to justify them, and work to raise awareness to overcome the opposition that Chile has historically had in the development of thermal regulations.

A perfected regulatory system and a modern quality accreditation system, should generate the synergies necessary to improve housing quality in Chile. This should serve as the base and driving element of an entire process of development and innovation leading to new products, processes and services, designed to serve a market with higher quality demands. At the same time, the R&D work in Chile should be formulated depending on the social objectives of limiting energy demand and reducing energy consumption in the buildings sector, and not skipping stages. Energy demand in the housing stock in Chile is excessively high; the first challenge should be to reduce that demand.

R&D work should focus, preferably, on the development of technologies to improve the supply available on the market of materials, building systems and conventional facilities. Then in successive stages, work should move toward more complex objectives, prior to which the necessary capabilities should be generated, such as zero energy (EEC) or net-energy building (EEN) goals.

To grow, the country needs greater amounts of energy and to disengage its economic growth dynamic from that of energy consumption. The challenge

of Chile today is to have sufficient, competitive energy resources and improve the performance of energy use in all sectors, particularly in the buildings sector. The country has made efforts to improve the energy and environmental condition of its buildings, with better and worse results; it shows progress that compares well with the rest of the countries in Latin America, and not as well with the countries with which it wishes to compare itself in Europe and Asia. Also, it shows asymmetrical progress, every time that important issues, such as airtightness, ventilation and hygrothermia, are not yet considered as part of the equation for the thermal and environmental improvement of buildings. The quality and energy efficiency of its residential buildings do not have the level that society currently demands in Chile, considering the country's present degree of technological, social and economic development.

It is assumed then, to be of strategic importance, the ability to implement the development plan that is proposed, in order in the year 2025 to have a supply of housing buildings with socially acceptable energy performance, which is obtained, as defined in this work, when minimum optimum energy consumption is achieved, without degrading indoor comfort and with low environmental impact.

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ANNEXES

1.0. INTRODUCTION

This document presents the results of doctoral work conducted at the Center of Research in Architecture and Climate at the Catholic University of Louvain, Belgium. This work was undertaken within the framework of an international cooperation agreement between the Catholic University of Louvain and the University of the Bío-Bío and the Catholic University of Chile, for the creation and development in Chile of a research team in architecture and sustainable construction, under the guidance and direction of the Architecture and Climate group. The cooperation agreement envisaged, among other actions: the development of human resources at the master and doctoral levels; the creation of laboratory infrastructure to support research processes in buildings physics; and the creation of research programs focused the country's needs in this area (UCL, 1997).

This author was initiated into the cultivation of research in building physics in the year 1985, in the then newly-created Center for Research in Architecture and Construction (CEDAC), at the University of the Bío-Bío, a pioneer center in the development of this discipline in Chile, under the direction of the National Prize in Architecture winner, Professor Roberto Goycoolea Infante. During my career I have been involved in the creation of laboratory facilities for the development of research in building physics in Chile, and in the development of experimental research on hytrothermal and energy improvements in buildings. During the past 25 years I have conducted research funded by Fondecyt, Fondef, Fontec, Innova, among others, which have resulted in patents, publications, and contributions to conferences and journals. Currently and since 2008, I have served as director of and senior researcher at the Center for Research in Construction Technologies at the University of the Bío-Bío, CITEC UBB.

The year 2002, as part of the same agreement, this author completed a master's degree program. The thesis dealt with the "development of test modules for experimental work in physics applied to buildings in Chile." In said work, the technical information necessary to design, implement and operate test modules or "Test Cells" was developed for experimental analysis of transport phenomena (HAM Transport) under real climate of prototypes of natural size constructive elements. These units are currently available at CITEC UBB and are the first and only of their kind in Chile today.

In the year 2012, I started this doctoral thesis work, related to the theme of energy and environmental quality of dwellings in Chile. At the time that the need to modify standards of thermal insulation in buildings, introduce other standards and, in general, upgrade and modernize rules and ordinances, was being discussed in the country, I felt it was time for a critical analysis of the trends, achievements and remaining challenges in energy quality in housing in Chile. This work could in addition relate with my contribution to the development of research in building physics in Chile.

Knowledge of achievements and pending challenges, raised the need to first know the current quality level of housing stock constructions, the existing gaps, and create hypotheses as to the causes. To that end, a baseline study of energy quality was undertaken of new housing stock. This was a large-scale diagnostic study, which combined the use of experimental techniques and numerical simulation, such as had never been carried out in Chile. Subsequently, the work considered a critical review of what has made Chile from the decade of the 80 in different areas, a process in which I participated as an actor from the academic world. In particular, achievements and remaining challenges are reviewed in the areas of research and technological innovation; in the areas of creation of infrastructure of laboratories for

research processes, transfer and certification of technologies; and in the areas of development of construction standards and ordinances. Finally, a strategic 10-year-plan is designed and proposed with the goal of improving the energy and environmental performance of housing stock in Chile.

Is it possible to learn from past experience and what are the main challenges in the field of research, regulations, training, quality control, policies, and others, and what recommendations can be made in these areas as a result of this study? These are issues which this thesis discusses, bearing in mind the country context, previously undertaken work, and a review of international research.

This chapter introduces the technological and social context of the thesis, the motives and problems that give rise to the research, and its objectives and the methodological approach used to achieve them. The state of the energy quality of housing stock in Chile, energy consumption structure in the building sector, and projections of energy demand of Chile are analyzed. Lastly, the research questions and hypotheses deduced from said analysis, and the scheme and investigation process enabling them to be contrasted are presented.

1.1 . General Background

1.1.1. Energy quality and demand of buildings

Buildings are essential components of society and the economy. They provide safe and thermally protected spaces and environments for human activity. Simply from an energy perspective, the building can be conceptualized, as a technological product that is designed and created to deliver services that require energy. Currently, 45% of energy generated

worldwide is being used to heat, cool, illuminate and ventilate buildings. It follows that 50% of global warming is caused by the consumption of fossil fuels in buildings (The Aalborg Commitments, 1994). In Chile, the situation is not very different: the building sector is responsible for 26% of energy end-use, 34% of solid waste generation, 33% of greenhouse gas emissions, and 6% of water use (Minvu, 2013). As a result, the energy demands of buildings have, in addition, important ethical and social dimensions. For these reasons it is required that buildings today have acceptable levels of social performance, for the benefit of the users and the communities in which they are located (Meacham, B. J. et al 2002).

The Inter-jurisdictional Regulatory Collaboration Committee (IRCC) defines socially acceptable energy performance as "the condition that is obtained when optimum minimum energy consumption is achieved without degrading interior comfort and with low environmental impact" (IRCC, 1988). Wouters, (Wouters, P. 2000), defines building energy quality in relation to indoor climate, as "the condition that results when levels of indoor building climate appropriate for users are achieved with limited or minimal use of energy". From these details it can be deduced that: the energy quality of a building in relation to indoor climate is defined qualitatively in terms of compliance, by the amount of energy that is required to achieve comfort and, that acceptable energy quality is attained when socially acceptable energy performance is achieved.

These basic definitions pose at least two fundamental issues: What is the optimal minimum energy? And, how are minimum requirements established, as well as regulatory controls to ensure their compliance? There is no simple answer, whenever complex, interacting social, cultural and economic variables are involved, which are directly related to society's economic and technological capacity, its degree of maturity, and quality expectations. In

practice, to establish minimum requirements for energy performance raises the problem of optimizing the relationship between the service of providing thermal comfort and the amount of energy and costs that the building demands for those purposes. The precise solution always harmonizes variables of building design with climatic and economic variables, and quality aspirations.

In consequence, the assessment of the thermal quality of buildings is directly related to the amount of energy that the same building requires to provide comfort, this is with its demand for energy (kWh/m²year), an indicator that measures the ability of the passive design to limit energy use. This indicator is used in this thesis to measure and evaluate the energy quality of housing buildings, the objects of study.

From the point of view of energy, the building can be considered as a thermodynamic system, subjected on a permanent basis to multiple and varied physical influences. Buildings are a system limited by a diabatic covering or enclosure through which energy and mass are exchanged dynamically, processes which are known as "HAM Transport" (Hartwig M. Künzel, 1995). Exchanges are mobilized by temperature potentials, and by steam and air pressure. Type and amount are determined by interior and exterior climate variables, and by the facilities planned for the thermo-environmental conditioning of the building. Phenomena that explain the ostensible variation in energy demand of buildings with the climate and quality of the design and implementation of its covering.

The Sankey diagram in Figure 1.1, shows the energy balance of a building during a heating regime. The theoretical net heat demand of a building consists of two parts. The first corresponds to transmission losses, which are determined by the construction design, thermal conductivity and thickness of

the layers of the building envelope's constituent materials. They are normally synthesized using the thermal transmittance indicator U (W/m²K). The second part is due to ventilation losses, which are determined by the devices provided for ventilation, and air leakage, which is in turn determined by the air permeability properties of the envelope. They are usually characterized by the indicator n50 (1/h). In this structure, the energy demand (kWh/m²year), passive design aptitude indicator, and final factor to optimize to improve energy quality, are defined by both kinds of loss, and by internal and external heat contributions, variables which should be addressed in order to reduce energy demand to optimal minimum values.

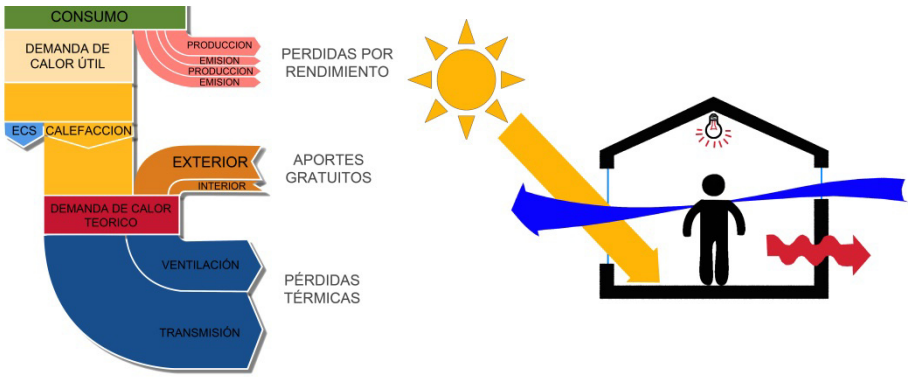


Figure 1.1: Diagram of the energy balance of a typical building in heat regime.

The energy quality of the buildings in each country depends on its economic capacity, of course, but also on the state of the technique and art of designing and building, on the state of the research in and regulations on thermal and environmental protection that govern the design and construction of buildings, among other important factors.

What is the state of these matters in Chile, as important foci of this thesis? In this regard:

1.1.2. Energy quality of buildings, problems and challenges

The demand for useful heat for the thermal conditioning of dwellings in Chile varies visibly with climate. One would expect, therefore, a similar variation in the energy quality of the buildings. This is not the case; Figure 1.2 shows the evolution of energy demand for the conditioning of a typical brick masonry residential construction, in heating and cooling service, in seven Chilean cities, which are representative of the thermal zones which define the country's thermal regulations. The case considers thermal insulation adjusted to the requirements of the regulations for each zone, and burdens from air leakage according to the airtightness characteristics of this type of building, which were determined experimentally during this thesis project.

In areas with primary heating demands, the zone of most significance in the national territory, the energy required to heat enclosed areas varies between 133 and 484 kWh/m²year; standards that are today considered excessively high. These levels are from 50% to 200% higher in distinct areas than the buildings should have if their enclosures had optimal thermal protection, as is established in the diagnostic phase of this work and confirmed by other recent studies (Damico et al, 2012; de Escorcia et al, 2012; Trebilcock, Celis & Miotto, 2012).

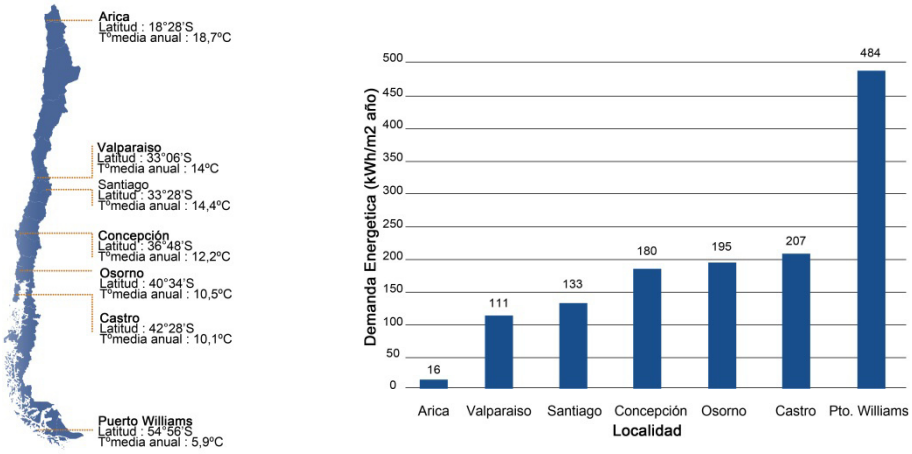


Figure 1.2: Current calculated energy demand (kWh/m²year), for the thermal conditioning of a masonry dwelling in different temperature zones of Chile.
Source: Fondef D 10 I 1025.

It is also clear that providing the same heating service has very different costs in distinct areas of the country.

Should it be so different?

This topic is currently being discussed in Chile; these differences indicate varying levels of climate stringency but, also, levels of thermal quality in buildings that do not correspond to the climatic requirements of each zone. There are two aspects that are most critical: the thermal insulation of envelopes and the airtightness characteristics of buildings. As regards the thermal insulation of the envelope: Table 1.3 presents the thermal transmittance limit requirements for building enclosure complexes, established by the thermal regulation of Chile, and comparisons with studies and other construction ordinances. Figure 1.4 shows the structure of materials and predominant systems used in dwelling walls in Chile. Figure 1.5 explains different masonry and concrete wall designs, the two most commonly used construction systems in Chile

Table 1.3: A comparison of thermal transmittance requirements for building enclosure complexes, U value (W/m² K). Recommendations according to sources on the different temperature zones of Chile and comparisons with the requirements for comparable temperature zones in Spain.

Zona Térmica	Reglamentación térmica	NCh 1079 (2008)	Manual de Diseño para la EE en Vivienda Social (2009)	Fondef D10I1025 (2013)	Manual de Diseño Pasivo y EE en Edificaciones Públicas (2012)	Código Técnico Edificación España (2007)
1	4,0	0,8-2,0	0,8-2,0	0,8-2,0	0,8-2,0	-
2	3,0	0,6-2,0	0,6-2,0	0,6-2,0	0,6-2,0	-
3	1,8	0,6-0,8	0,6-0,8	0,6-0,8	0,6-0,8	0,73
4	1,7	0,3-0,8	0,3-0,8	0,3-0,8	0,3-0,8	0,66
5	1,6	0,5-0,6	0,5-0,6	0,5-0,6	0,5-0,6	0,57
6	1,1	0,4-0,6	0,4-0,6	0,4-0,6	0,4-0,6	-
7	0,6	0,3	0,3	0,3	0,3	-

Source: Created by the author with data from different sources

Heavy construction in concrete and ceramic brick masonry made up nearly 70% of the building permits for housing in 2011 and shows a slow decline (INE, 2011). In the year 2007, before the implementation of thermal regulation, this kind of construction occupied the 74% of the market. Lightweight construction in wood increased from 13 to 17% in this period and slowly light industrialized systems that are used alone or combined with traditional systems are incorporated. These include systems based on SIP (Structural Insulated Panel) panels, EIFS (External Insulation & Finish System), and others that utilize different materials and technologies. The most common use wood panels and/or metal elements and expanded or injected insulating material expanded.

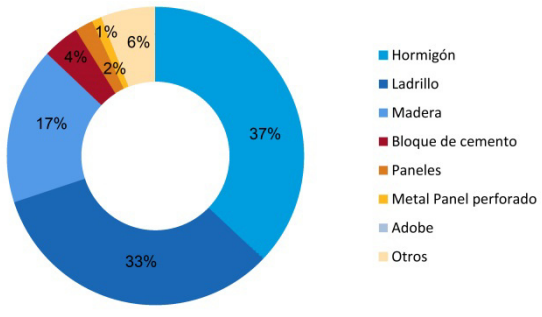


Figure 1.4: Materials and predominant housing construction systems in 2011.
Source: INE Chile

These systems arise at the beginning of the first decade of the 21st century, in response to problems in productivity and housing quality, and begin to be incorporated with greater frequency in Chile only in 2007, when thermal regulation comes into force. However, in Chile these systems, still do not exceed in 10% of the market for residential construction.

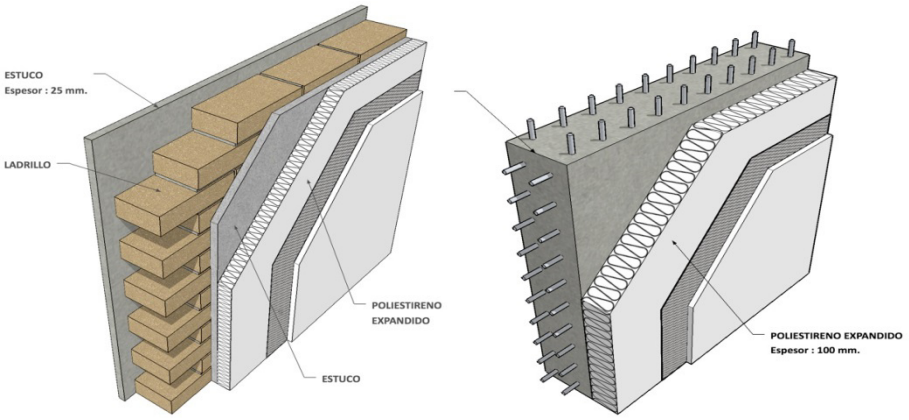


Figure 1.5: Typical masonry and concrete wall complexes in dwellings in Chile. Masonry typically consists of hollow, ceramic brick, 14cm thick by 29 cm long, with height varying between 7 and 14 cm. In 1st to 3rd temperature zones, it tends to be used alone or with stucco and the remaining zones with thermal reinforcements of different kinds and thickness to meet the demands of thermal regulations. Concrete walls pertain to a kind of reinforced wall of between 2400 and 2800 kg/m³ and from 10 to 25cm in thickness. In the first two temperature zones, it is often usually utilized without thermal reinforcement.

The thermal insulation standards that the regulations require do not compare well with those of other European ordinances that are in effect in comparable climates, or with the standards that Chilean studies have been recommending for the last several decades (Rodriguez, G. 1973; Bobadilla, A. and others 1986; Bobadilla, A. and others, 1991; Bustamante, W., 2010; D'Alençon, R. 2010; CITEC UBB, 2012a). In the 4th climate zone, in which Conception is the representative city, the Thermal Regulation establishes the maximum thermal transmittance for walls to be 1.7 W/m²K. Studies, some founded on

experimental evidence derived from field research and diagnosis of failures, recommend that transmittance limits not exceed 1.0 W/m²K (CITEC UBB, 2010a).

Clearly, thermal insulation standards are not adjusted to the climatic requirements of each locality. They are incompatible with the current needs of minimum optimal energy use, in particular in the south-central and more populated areas of the country. In this way substantive differences can be perceived in the ability of buildings to limit energy demand, that is, in suitability for use in distinct areas as shown in Table 1.3 . This objective situation sheds some light on the energy quality of the buildings in Chile, and on the existence of gaps in quality depending on area or location in the country, gaps that require further study to better orient the energy improvement plans for the country's building stock.

The thermal insulation requirements in the building ordinance in Chile must be adjusted to better respond to the social needs of minimal energy use in buildings; this is an important pending challenge in Chile today. Alternately, the thermal zoning does not reflect climate subdivision in Chile. It ignores the behavior of climate variables that are important for the design of hygrothermal buildings, such as thermal oscillation, humidity and wind speeds, as explained in greater detail in chapter 5. Its use is misleading, for which reason its application in energy demand studies in many Chilean cities has been called into question.

With regard to building airtightness, another important problematic front in Chile: Figure 1.6 presents the base line of air leakage, according to the primary construction systems. Figure 1.7 shows the frequency curve of airtightness in housing stock registered between 2007 and 2010 in Chile.

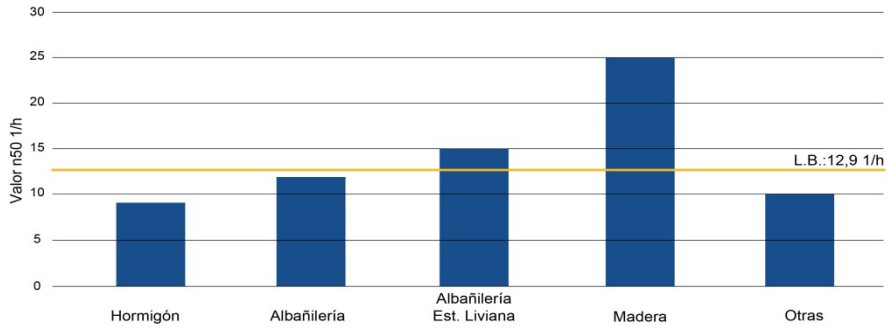


Figure 1.6: Base Line of air leakage in the main construction systems in Chile. Source: Fondef D10 I 1025.

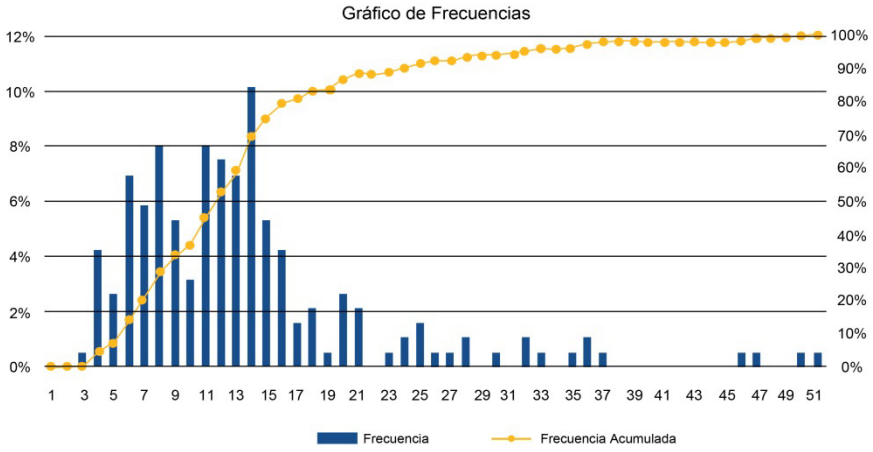


Figure 1.7: Frequency of airtightness of dwelling stock built between 2007 and 2010 in Chile. Source: Fondef D10 I 1025.

In Chile, there are no regulations for governing the air airtightness of buildings, and with it, the thermal loads associated with air leakage. In consequence, an important component of the energy demand for the thermal conditioning of a dwelling, which in some cases in Chile can represent 60%, is not controlled (CITEC UBB, DECON UC, 2010; Ossio, F. and others 2012). All the measures, starting with the establishment of standards, designs, technologies and regulations, in Chile have aimed only at the

reduction in transmission losses, which seriously affects the efficiency and profitability of the actions being taken to improve the energy quality of buildings in the country.

At present, the average airtightness in residential construction in Chile, its n50 value, is located at the 12.9 1/h level. Expected average values for stock are in the range of 11.1 and 14.7 with 95% confidence. These indicators illustrate the degree of air airtightness of buildings in Chile, the state of design and building techniques, and energy quality of housing stock. Less than 5% of stock possess the 3 1/h reference standard for air airtightness limits in several European countries. At present, the standard for timber construction is particularly critical with airtightness indices around 24.6 1/h. All indicators demonstrate the absence or deficient use of sealing techniques and poor quality of implementation, aspects that should be improved to ensure acceptable energy performance in this and other types of construction used in Chile. As a result, it is also necessary to establish limits of air airtightness for buildings in Chile.

It is expected that this situation will be overcome in part by mid-2014, once the results of Fondef project D10I1025 are put into service. This project was mandated by the Ministries of Housing and Public Works, in order to define the airtightness requirements that will govern future buildings in Chile, along with a package of technological solutions differentiated by climatic zone and construction type, so as to facilitate their compliance. [1]

[1] FONDEF Project D10 I 1025: "Establishment of classes of infiltration acceptable for buildings of Chile". Work mandated by the Ministries of Housing and Public Works of Chile, whose Director is the author of this thesis. The objective of the project is to establish the requirements of air airtightness that will govern future constructions in Chile, carried out during the 2012-2014 period. The project involves zoning the national territory by infiltration degree-day along with the development of technical solutions and support to guide the design, construction and quality control of buildings, to achieve airtightness adjusted to the needs of

The lack of knowledge about the airtightness characteristics of the building has had other important consequences in Chile. To calculate the energy demands of residential buildings and assign them an energy efficiency rating, in Chile the Ministry of Housing's CCLT_CL_V2 and CEV_V_1.0 norms, which are considered official for these purposes. These tools use a standard infiltration value equal to one air change per hour, regardless of construction type, geographical location or time of year. This assumes the same air airtightness characteristics for all buildings in Chile, and the same energy losses due to infiltration for all buildings in the same locality. This is a limitation of the tools which affects their ability to estimate energy quality. In the same way, distortions are produced in comparative quality evaluation of alternatives when it is incorrectly assumed that all buildings in the same place have the same demand from air leakage. On the other hand, the use of advanced simulation programs such as TAS, TRANSYS, and ENERGY PLUS, that do not have this limitation, in the absence of reliable information on building airtightness, have always been used assuming default airtightness values in a relatively arbitrary manner. At the least, there is no base of information from the field.

In summary: the lack of information on the airtightness properties of buildings, coupled with the limitations of the available tools, have impeded our understanding of the energy burden associated with air leakage and its effective impact on the energy demand of dwellings. For these reasons, it has been impossible to obtain at least a more accurate appraisal of the base line of energy quality in housing in Chile. In this way, considering that any

optimal minimum use of energy in the buildings sector in Chile. In the middle of 2013, the study revealed the base line of the air infiltration in Chile, and infiltrations standardized or normalized by residential construction type in the 54 provincial capitals of Chile. Base information for the development of this thesis. In the month of March 2014, a draft of Technical Standard MINVU TMR 011/3 2014 which incorporates airtightness requirements went out for public consultation. It is expected that by the end of 2014 it is fully in force in Chile.

process of quality improvement should, necessarily, begin by determining the real level of initial quality, which can be assumed as a base reference, it is essential to first know the impact of air leakage on the energy quality of buildings in Chile . This important challenge is one of the primary objectives of this thesis.

The deficiencies and difficulties identified seem to explain the moderate and almost non-existent progress in the reduction of energy intended for the thermal conditioning of buildings. In practice, the savings that are actually achieved, that is, measured, in many cases are quite smaller than projected at the time decisions are made on investments in thermal improvements (CITEC UBB, 2010). High air leakage that is very undervalued in Chile when making calculations and predictions of energy demand, the use of thermal protection that is unrelated to climatic requirements or the need for minimal energy use, the low requirement levels of thermal regulation, the absence of controls on service quality, among other causes, explain many of these bad results. In this way, the effectiveness and profitability of the actions being taken to improve the energy quality of buildings in Chile and generate savings, is seriously being affected.

Weaknesses in the thermal insulation of envelopes are the main cause in Chile in addition to the occurrence of surface and interstitial condensation phenomena (CITEC UBB, 2010b). Condensation is the main cause of defects in the windowpanes of the buildings from the Santiago Metropolitan Region to the South of the country. Condensation causes the emergence of fungi, the deterioration of cladding, rot, structural damage in the most serious cases, and always a decrease in the envelope's insulating capacity, problems that are frequently reported through social media in Chile. The primary causes of this problem are the reduced thermo-insulating capacity of the envelope and the indiscriminate use of new materials, whose hydro- and

thermo-physical properties are unknown, which would seem to be incompatible with the designs of envelopes used in Chile (CITEC UBB, 2013a and 2013b). The fact is that most of the solutions for building envelopes fail to correctly relate the physical properties of the materials with the design, and the design with the different climates in the territory. The materials used have changed; the level of thermal insulation is somewhat higher, although it still seems insufficient. However, envelope designs remain virtually the same and are used almost completely independent of the climatic characteristics of place.

In summary: Chile has shown progress in the environmental and energy improvement of its buildings which are important at the Latin American level, but less so if compared with the state of similar developments worldwide. The country also shows asymmetrical progress, any time that important issues such as airtightness, ventilation and hygrothermia are not yet considered as part of the equation in the thermal and environmental improvement of buildings. The quality and energy efficiency of its buildings are at levels that society currently requires, not at least at the country's present level of technological, social and economic development.

This thesis aims to analyze the energy quality of housing being built in Chile today. It first proposes to determine the base line for the energy quality of the mass supplied buildings and the existing gaps, based on the measurement of a representative sample of housing stock. Then, with this knowledge, a critical analysis of the trends, achievements and remaining challenges in the energy and environmental quality of buildings in Chile will be performed to establish the factors that explain the existing level of quality. Finally, it proposes a plan of strategic actions for the next 10 years leading to the improvement of the energy and environmental quality of dwellings in Chile,

bearing in mind the country context, experience and previously undertaken work, and international developments in the sector.

1.1.3. Energy demand and projections in the World and Chile

Global primary energy demand rose 5% in 2010, reaching a record figure of 500 quadrillion BTUs. Non-OECD countries were responsible for 30%, caused 80% of the increase in demand and will increasingly continue to set the dynamics of the energy markets. According to the WEO report (World Energy Outlook, 2013), it is expected that between 2010 and 2040 the world economy will progress at an average annual rate of 2.8%, that the world's population will grow 25% and reach nine billion people, and that the energy demand will reach 700 quadrillion BTUs, a 35% increase over 2010.

According to WEO estimates, during this period, 90% of the population increase, 70% of the increase in economic output, and 90% of the increase in energy demand will be attributable to non-OECD countries. China will strengthen its position as the number one energy consumer in the world: in 2040, it will use approximately 70% more energy that the United States, the world's number two consumer. Although, at this time, the per capita energy consumption in China will be less than half of that in the United States. The growth rates of energy consumption in India, Indonesia, Brazil and the Middle East will be even faster than those in China (Exxon Mobil, 2013).

The United States will lead economic growth in OECD countries, contributing more or less 25% of world GDP, followed by China with 20%, the rest of the members of the OECD 30%, and 25% non-OECD countries, which will be the fastest growing group. All considered, by the year 2040 the GDP should reach approximately120 trillion dollars (equivalent to the year 2005).

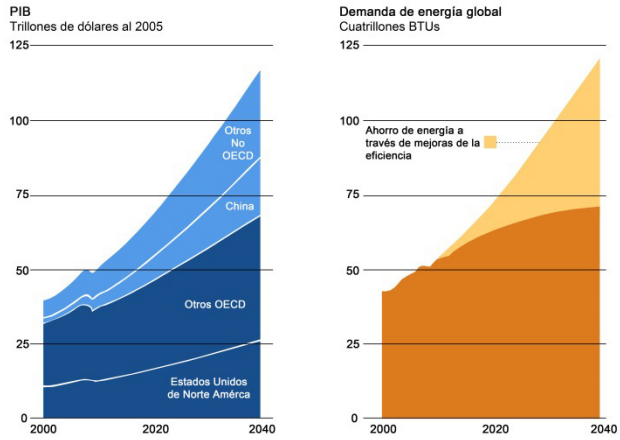


Figure 1.8: GDP projection and global energy demand 2010-2040.
Source: IEE World Energy Outlook 2013

The WEO projections wager that the growth in energy demand does not increase so dramatically with economic growth. This situation is expected as a result of the decrease in energy intensity or amount of energy used to create a unit of GDP product. This ability to expand economic prosperity with relatively moderate growth in energy demand, should result from at least three key factors: greater efficiency in energy use in all sectors, through the implementation of more efficient technologies and management and production systems; greater consumer education, and; the development and application of more stringent standards and regulations.

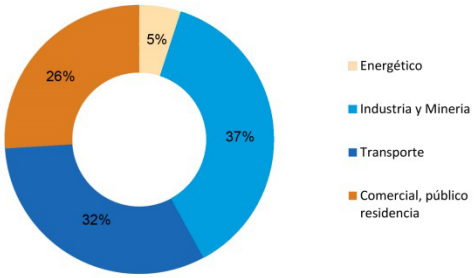


Figure 1.9: Sectoral energy consumption in Chile 2011.
Source: CNE

These factors should combine to reduce the demand for energy and effectively decouple economic growth, especially in countries with emerging economies. According to this scenario, with regards to the situation without intervention, an energy savings could be generated of approximately 500 quadrillion BTUs. Energy efficiency should become established as the greatest source of energy. The primary source of energy for the future is to continue using energy in a more efficient manner each day.

On the other hand, the preponderance of the fossil fuels will decrease, but their demand, as specialists claim, will continue to play an important role for much longer. Although the demand for all fuels will increase, the proportion of fossil fuels in worldwide primary energy consumption will drop slightly, from 81% in 2010 to 75% in 2035; natural gas will be the only fossil fuel to increase its presence in the global energy mix in the period up to 2040 (IEA, 2013). In the electricity sector, technologies based on renewable energies, headed by hydro- and wind power, will represent half of the new capacity installed to meet the growing demand.

In the period between 1986 and 1998, Chile grew at a rate of 7.4 %. The country's growth declined between 1999 and 2009 to a rate of 3.3 %, and only just recovered its growth capacity in the year 2010. In the year 2012, it grew at a rate of 5.6 % and its projected growth for the next few years is estimated at around 5%, among the highest in OECD countries. The GDP grew threefold in the last three decades, and it is expected that by the end of this decade, Chile attains the developed country status to which it aspires. This growth however has been accompanied by a significant increase in energy demand, a situation that is expected to revert in the present decade, effectively uncoupling energy consumption from the evolution of the GDP. It is hoped that this situation will be achieved, as set out by the Chilean Agency for Energy Efficiency, an entity which brings together public-private

collaboration with this objective, by acting directly in various consumption sectors with diverse projects and political, technological and educational actions (Achee, 2013).

In the year 2011, energy demand in Chile reached the 275,850 teracalories (1.09 quadrillion BTUs), a figure that represented approximately 0.2 percent of global demand. By sector: the Industrial and Mining Sector continues to lead consumption with 37 percent, followed respectively by the Transportation Sector (32.1 %); Commercial Sector, Public and Residential (26.3 %) and Energy Sector (4.6 %) (MINE, 2013a).

This demand is currently covered with a poorly diversified energy matrix, dependent at the primary level on only seven energy sources: oil (34.7%), coal (20.8%), wood and its derivatives (19.7%), gas (18.2 %), hydroelectricity (6.4%), wind (0.1 %) and biogas (0.04 %). Fossil fuels and wood serve more than 90% of the energy needs in Chile; renewable energy sources do not yet occupy important shares.

However, there is an interest in changing this structure; Law 20,257 on the Promotion of Non-Conventional Renewable Energies (NCRE) (except hydroelectricity) establishes a goal of 10% NCRE by 2024, led by wind power, solar energy and biogas especially. Many specialists agree that this goal is still insufficient given the huge potential for solar energy in the north of Chile (MINE, 2013b and 2013c).

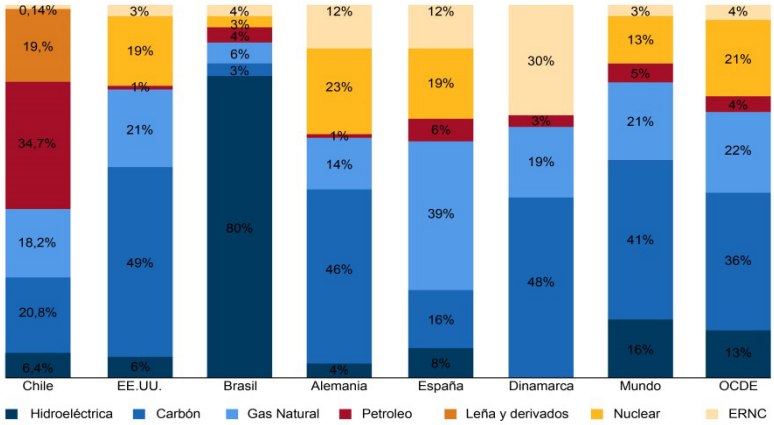


Figure 1.9: Structure of Chile's energy matrix compared to those of other nations. Source: Created by the author with data from the CNE Chile and the EIA.

Hydroelectricity has suffered a major setback in recent years. According to reports from IMTrust (IMTrust, 2012), the generation of hydroelectricity decreased 3% in 2012 compared to 2011, producing 20,104 GWh during the year, and contributing only 40% of the total national power generated. Hydroelectric plants have not had such low production since the year 2000, when 18,323 GWh were generated. Successive seasons with low rainfall and low levels of snow in the high mountains are the main causes of the progressive decline in hydroelectric power plant participation in the generation of energy during the last few years. In Chile, efforts are being made to increase in the participation of hydroelectricity through new plants whose projects currently face severe restrictions, which casts doubt on the growth projections of hydroelectricity in the national energy matrix.

The National Energy Strategy 2012-2030 aspires that in this period traditional hydroelectricity will only achieve 45 to 48% participation, so as to reduce the high dependence on fossil fuels (MINE, 2013c). This situation seriously affects national energy security, as was dramatically demonstrated in the winter of 2007 in which distributors of Argentine gas inopportunely

cut off the supply to Chile, due to a cold wave in that neighboring nation. As a result of the same event, much of the central area of the country went for several weeks without basic services and many companies had to suspend their activities, which seriously affected the economic activity and quality of life of an important part of the population.

In 2011, Chile imported 97% of its oil needs, 72% of gas needs, and 95% of its coal needs. 68% of energy was purchased abroad that year, which makes the country highly dependent on energy imports and price fluctuations. Exogenous issues such as global supply, in the case of hydrocarbons and political instability in the Persian Gulf area, pose additional problems.

On the other hand, at present the country has a total installed capacity of 16,970 MW, double the capacity of a decade ago, but still inadequate. 73.6 % corresponds to the Central Grid (SIC), 25.6% to the Greater Northern Grid (SING), and 0.8% to the medium-sized systems of Aysén and Magallanes. The peak demand during 2011 reached 6,881 MW in the SIC, whereas in the SING it was 2,162 MW (MINE, 2012).

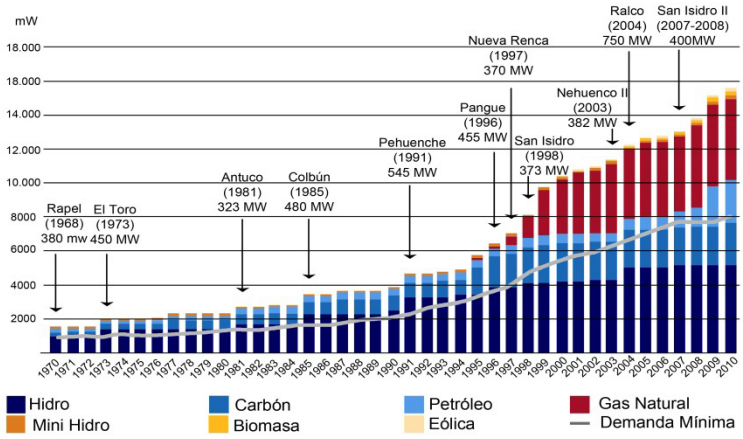


Figure 1.10: Installation of electricity generation capacity 1970-2010.
Source CNE Chile.

The gross generation during 2011 was 61,973 GWh, which shows 6.0% growth compared with the year 2010. This is explained mainly by increased generation of thermal plants. On the other hand, by 2020 electricity consumption is projected to grow by around 6 to 7%, which means about 100 thousand GWh of total demand for electrical energy to said year. This will require increasing the supply by more than 8,000 MW in new generation projects (MINE, 2012).

This situation obliges growth at twice the rate experienced in the last decade, a complex task considering the new legal regulations concerning the environment that have been in place since the year 2007. These have substantially raised production standards and are added to strong, internally supported protests that are opposed to the installation of new plants because of environmental safety. In Chile, large hydroelectric projects in the Aysén and Magallanes Regions and thermal power plants in the Biobío and Atacama Regions are paralyzed for these reasons, which has increased the marginal costs of power generation and the price of electricity.

1.1.4. Energy consumption in the building sector in Chile

The national energy balance in 2011 showed that 71,314 teracalories went to the commercial, public and residential sector, 77% of which was destined for the residential buildings subsector. The main use of energy in this sector, according to the author's estimates based on data from the National Energy Commission, break down as follows: heating (57%); cooking (28%); lighting and appliances (13%), and cooling approximately 1% (MINE 2013a).

The use of air conditioning for cooling is on the rise in Chile, especially in the top fifth income bracket, but still represents a very small fraction of the

energy consumed in the housing subsector. Encinas (2011) estimates that cooling occurs in 2% of housing stock, based on market studies conducted by the Center for Public Policy at the Pontifical Catholic University of Chile in 2010. This demand is concentrated, especially in apartment buildings and housing of high economic value in the central zone, with relatively high thermal insulation standards (U: 0.45 W/m² K), with solar insufficient protection and/or deficient strategies for natural ventilation.

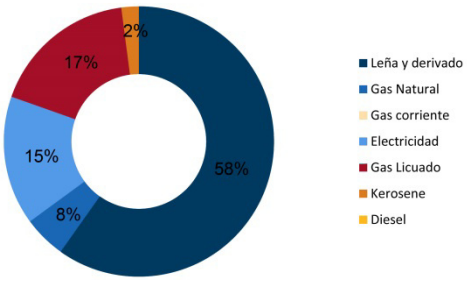


Figure 1.11: Use of fuels in the housing sector in Chile 2011.
Source: CNE

Large demands for cooling are also generated in some sectors of the Santiago Metropolitan Region, due to the low or non-existent potential for natural cooling in some localities. These sectors are characterized by average air speeds in January of 2.6 m/s, very close to calm conditions, with an average temperature of 20.9º C (Quinta Normal reference station) (INN, 2008).

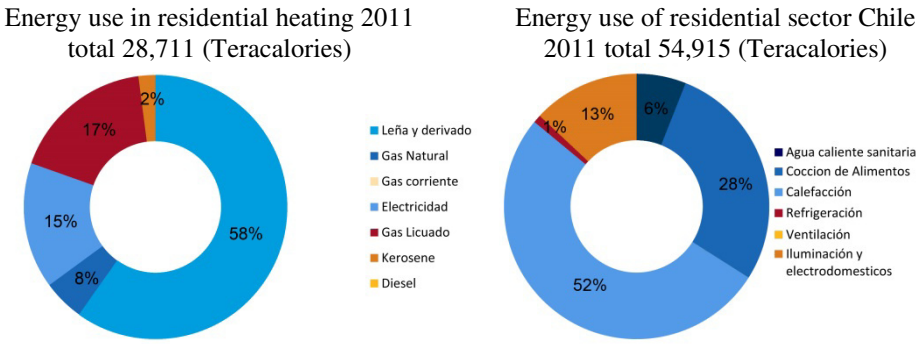


Figure 1.12: Use of energies in homes and
for heating purposes in Chile 2011. Source: CNE

The energies most used in Chile for heating purposes are wood and its derivatives (88%), followed by gas (6%), and kerosene (4%). This highlights the massive use of firewood in Chile and the serious environmental pollution problems generated by its use in cities in the south central region of the country. Currently, the burning of wood is the main pollution source of heavy (PM10) and fine (PM2.5) particulate matter in cities such as Temuco, Chillán, Concepción, and Osorno (Chile Environment, 2008) (CDT & Arq. Energy, 2012).

In the year 2012, on average the concentration of particulate matter was exceeded one of every four days in various cities in the south of the country. At times, concentration levels reached as high as 1,000 μg/m³N (Terra Time 2013). This situation obligated the declaration of more than 21 alerts in 2013, with the corresponding suspension and strict prohibition of wood stove use of for long periods of time. The source of the problem lies in the burning of damp firewood, equipment with obsolete technology, informal wood suppliers, use of uncertified wood, meteorological events with low levels of ventilation during certain times in the winter season.

Under these conditions, the massive use of firewood, is generating serious air pollution problems, degradation of natural forests, and deforestation. Recently, in order to limit the use of firewood, reduce environmental impacts, and improve thermal comfort, several initiatives are being carried out. One of them, led by the MINVU and trade associations in the construction industry, involves the development of designs for more energy efficient subsidized housing that is better adapted to outdoor climate conditions and household use practices (Trebilcock et al., 2012). Other initiatives concentrate on educating the public about the responsible and efficient use of energy, technology change, and the updating of standards and regulations conducive to reducing the negative impact of firewood use on the environment and the health of the population.

1.2. Objectives and methodology

1.2.1. General objective

This thesis is on the topic of the energy and environmental quality in residential buildings in Chile. Its general objective can be described as follows:

"To perform a critical analysis of the trends, achievements and remaining challenges in energy and environmental quality in relation to indoor climate in buildings intended for housing in Chile, and its relationship with different technological and social factors that explain and condition, such as construction ordinances, development research, infrastructure and technological equipment for research, construction technologies, level of economic development, and others."

For all effects and purposes of this work, appropriate energy and environmental quality, referring to the indoor climate and energy efficiency of a building, is understood to be the condition that is obtained when: indoor climate levels are achieved in the building that are appropriate for its users with limited or minimal use of energy. Discussions about what is meant by "minimal use of energy" and "appropriate quality conditions" in the Chilean context form an important part of the work.

A strategic, 10-year plan is designed and proposed with the aim of improving the energy and environmental performance of residential buildings in Chile, based on real knowledge of the energy quality of housing stock currently being built, which resulted from the evaluation of: a representative sample of the homes built in 2011 in each of the 54 provincial capitals of Chile, and national trends, achievements and future challenges.

1.2.2. Research Questions

A building of quality must bring together the features that meet the needs of its users; it must accommodate their physical, physiological and psychological requirements, which are the very essence of the residential building, and provide appropriate comfort conditions. In the same way, today it is required that buildings demonstrate their energy efficiency and sustainability performance. Indeed, in this day and age society demands buildings that are increasingly energy efficient, safe, and sustainable.

Chile is an energy-dependent country that spends almost a third of the energy it produces in its building sector. As a result, the country must worry not only about saving energy but also about using it efficiently, for which reason it is necessary to have a housing stock with appropriate thermal quality, a challenge of Chile today. Historically, with few exceptions, the concern of housing policy has always been to privilege the construction of the maximum possible floor area at the expense of quality. In addition, the vision of quality has been very biased and associated almost exclusively with size, structural mechanical attributes, and rather aesthetic and functional characteristics. As a result of the evaluation of the quality of residential buildings, other features also strongly associated with the quality of habitability, such as thermal and acoustic insulation, become requirements and reasons for concern recently in the late 90s in Chile.

So, probably more slowly, and in terms other than those society would like, the scenario in Chile has changed for the benefit of improving the energy quality of the housing stock. Provisions have been incorporated in the ordinances that look to limit energy losses in transmission and Chile is on the brink of incorporating a system of certification and labeling of energy efficiency in new dwellings, similar to the logic of the European Directive

on Energy Performance of Buildings (EPBD). A certification system applicable to previously built dwellings is soon to be launched, and a program is being developed that seeks to distribute 800,000 subsidies during the period 2010-2020 for the thermal refurbishment of the housing stock (Environmental Consultants, 2007). On another front, in the last decade basic and applied research has intensified, leading to the development of new materials, construction elements and processes that are justified based on energy efficiency. This has given rise to technological innovations and new products on the market. Chile's open economy has enabled the entry of new, supposedly more competitive materials and construction solutions that seek to position themselves in the domestic market, displacing traditional construction in masonry and concrete, which is less prepared to deal with energy regulations.

Building statistics, which have been processed and reported annually since 1932 by the National Statistics Institute INE, show that the structure of the construction systems used in Chile has indeed changed. There is an increasingly diverse structure, which is very positive and demonstrates healthy competition, and the progressive advance of light industrialized construction to different types of panels, to the detriment of traditional, more manual, heavy construction in concrete, block and brick.

In summary, dwelling design, especially of its envelope, as well as the materials used, is different from that observed in homes built prior to the seventies, especially in the south-central area of the country. The impression exists as well that modern buildings are more energy efficient and offer better quality indoor climate.

Is this a myth or a fact?

What changes in the thermal, hygrothermal, acoustic, and other properties and characteristics, have the materials and envelope designs had, and how have these changes impacted the energy efficiency and indoor climate of buildings in Chile?

Have all the solutions been successful? Which have been the most successful and why? What explains the unsuccessful cases? Are there technical reasons? Other causes?

What is the energy quality of the residential buildings the real estate market offers today in Chile, and how does this quality differ by construction type in the distinct provinces of Chile?

How does the energy quality of the housing offered on today's real estate market compare with that of the dwellings offered in the 90s, and how do both compare with the optimal minimum demand today?

What are the current existing gaps in quality and what explains those gaps?

How have research and development, technological infrastructure, and training needs in the area evolved, and how have they been met?

Is it possible to learn from past experience and what are the main challenges in the field of research, regulation, training, quality control, policies, and other, and what can be recommended in these areas as a result of this study?

This study aims to discuss all these issues, evaluate them and deliver recommendations on the work to be done in the next 10 years in Chile to

improve quality, bearing in mind the country context, previously completed work, and the current state of international research in the area.

1.2.3. The research focus of the thesis.

Different analytical techniques are use to respond to the questions posed by the thesis. The project is organized sequentially in blocks, based on specific intermediate objectives that are reported in the distinct chapters of this report.

Figure 1.13 presents the operating organization scheme of the thesis and its stages. It explains the process, steps and milestones necessary for the creation of a proposal for action plans and programs for the improvement of energy and environmental quality in residential construction in Chile. Figure 1.14 explains the methodological scheme used to establish the base line of energy quality in housing stock.

The overall work program consists in three stages: a diagnosis; the development and comparison of hypotheses, and; a third, the creation of a strategic development plan.

The objective of the first stage, the diagnosis, is to determine the level of quality of the dwelling that the market currently offers in Chile. It also presents the general development framework for the project and the current context in which it is carried out. It is separated into three chapters:

Chapter 1 presents the main elements of the problem to which this thesis is a response, in addition to others of context. The problem is summarized in the discussion about quality and energy demand of the residential buildings in different areas of Chile and the capacity that dwellings show to limit energy

demand. An explanation is given of the thesis objectives, research questions and methodological approach used to answer them and achieve the objectives.

Chapter 2 analyzes climate characteristics in the national territory, buildings constructed in 2012 in Chile, and the relationships between climate, design, energy demands, and construction technologies. The supply of real estate is studied in order to establish behaviors and patterns that explain the use of the different construction systems in each climatic zone and their convenience from the perspective of energy use optimization in the building sector.

Chapter 3 is devoted to the diagnosis of energy quality of the buildings currently offered on the Chilean market for residential use, and the establishment of gaps in quality. The base line of energy quality is determined for the stock of new dwellings in Chile, through the evaluation of representative samples of the housing stock built in 2011 in the country's 54 provincial capitals. A sample included 191 units representative of type and materiality of construction, and another 20 units, representative of housing architecture in Chile. Experimental techniques are used (Pressurization to assure the airtightness of the samples; numerical models (LBL Model) to link airtightness properties with the climatic characteristics of each province and obtain infiltration coefficients standardized by construction type and province, and; simulation techniques (Thermal Analysis Simulation Software) to determine the energy demand of the houses, by construction type, province, thermal zone, and the country total. This is the first time that this kind of work has been done in Chile considering the real airtightness of the housing stock. The gaps result from comparing the actual quality of the housing stock with reference qualities defined under the concept of limited or minimum use of energy. Levels are set using the techniques and methods proposed by this author (Bobadilla and others 2012). They were originally

developed by order of the Ministry of Public Works, for evaluating strategies for the passive design of commercial buildings in Chile, and later adapted for use in the measurement residential building performance. It is in this way that they are used in this thesis work, through the project Fondef D 09 I 1962 executed by CITEC UBB and DECON UC under the direction of this author between the years 2010 and 2013, by mandate of the Chilean Ministry of Housing (CITEC UBB & DECON UC 2010). From the analysis of gaps, a set of hypotheses is created about the causes of the object to be able to act on them through plans and actions that this thesis lastly proposes.

There are basically three cause hypotheses, which are addressed in respective chapters, namely: (1) The investigation leading to the development of new and better solutions in materials, construction elements and buildings has not known how to respond to the needs of industry and society; (2) The regulatory framework is weak and has not served well enough for the purposes of optimizing the use of energy in the building sector: limitations in its scope and performance criteria prevent it from making a better contribution and; (3) The laboratory infrastructure and tools available in the country to support both the processes of innovation and the development, of the application of standards and regulations, and training, is insufficient or unsuitable for the needs of current development.

The second stage, of development and comparison of hypotheses, aims to establish the causes and factors that explain the level of quality housing stock and the existing gaps. Retrospective analysis techniques were used on the basis of the observed effect, to go back in time to search for and analyze the causes that explain the existence of gaps. This stage is separated into three main chapters:

Chapter 4 presents and discusses the research and development work done in Chile from 1985 to 2012, in relation to the issue of the energy quality of housing. A cadaster is created. Characterization is completed of previously carried out research and the main construction technologies present on the market that have resulted from this work and/or processes of adaptation and technology transfer. An analysis is done of the evolution of the supply and demand of research papers, the committed investment, the type of research, its results and the existing deficits today considering the diagnosis.

Chapter 5 presents and discusses Chile's progress in the area of instruments and regulations to improve the energy quality of its housing stock. The existing legal framework is explained in regards to the planning, urbanization and construction of dwellings, as well as the different instruments for mandatory application in this field, such as regulations, norms, technical itemizations and other documents used from 1985 to 2013. The level of regulations, their character, the type and level of standards and implementation mechanisms are discussed. The presentation is made retrospectively in order to understand the progress over time, along with the difficulties and factors that limit the creation and installation of a modern building regulatory system in Chile.

Chapter 6 presents and discusses the advancements made in the area of creation of scientific-technological infrastructure in the area of buildings physics in Chile. In general, these include experimental facilities to promote the processes of knowledge creation, development and certification of materials and technologies. The history of the process of installation of capacities, and the motivations for its creation are explained and the main laboratories of Chile are identified and characterized. The main installed techniques and experimental work modules available in Chile are described and infrastructure deficits are identified, considering the incorporation of

new technical standards to the OGUC and the research and development needs not yet covered in the area.

The third stage, involves the design and development of a strategic development plan, which defines the main actions that Chile should implement in the next 10 years to improve the energy quality of its housing stock. This plan is deduced from the review and analysis of Chile's experience, the previously completed work, the current level of energy quality of the housing stock, and the opportunities and expectations for quality in Chilean society.

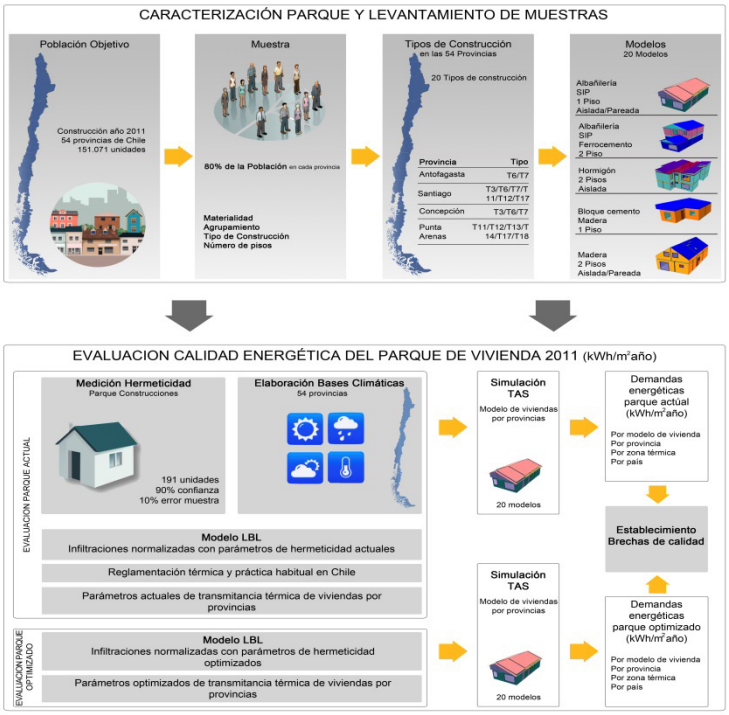


Figure 1.14: Process of development of quality judgments of building stock authorized in 2011 in Chile.

1.3. Chapter 1 Conclusions

Chile is an energy-dependent country, dangerously dependent. More than 70% of the energy that is used in Chile is purchased abroad. In 2011, Chile imported 97% of its oil needs, 72% of its gas needs and 95% of its coal needs. Also, energy use performance is low in all sectors of domestic consumption. The lack of access to reliable sources and networks of energy is certainly a dangerous limitation for sustainable social progress, for economic growth, and for the well-being of the population at present.

In order to grow, the country needs increasing amounts of energy and to disengage its economic growth dynamic from that of energy consumption. Consequently, the challenge of Chile today is to have sufficient, competitive energy resources, and improve energy use performance in all sectors, particularly in the buildings sector. Chile shows progress in making energy and environmental improvements to its buildings, which compares well with the rest of the countries of Latin America, but not as well with the countries it aspires to compare itself with in Europe and Asia. In addition, Chile shows asymmetrical progress, whenever important issues, such as airtightness, ventilation and hygrothermia, are not yet considered as part of the equation of the thermal and environmental improvement of buildings. The quality and energy efficiency of its buildings are not at levels that society currently requires, not at least at the country's present level of technological, social and economic development.

The country however has made efforts to improve the condition and environmental energy of its buildings, with best and worst results. The lack of information on important physical properties of the materials and buildings, coupled with other available analysis tools, have prevented a better vision of the energy quality of housing stock, which is the starting point of any improvement process. There is an urgent need for reliable information to design appropriate plans and actions leading to the effective optimization of energy consumption.

The same measures can improve the effectiveness of investments made to improve energy efficiency in Chile. This thesis project seeks to serves these purposes.

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2.0. CLIMATE AND RESIDENTIAL CONSTRUCTION TECHNOLOGIES IN CHILE

This chapter deals with the climate-building relationship in Chile and is divided into two main parts. In the first, a review is made of the different types of climate in Chile, of their zoning and potentialities for passive design. In the second part, results of work on characterizing housing stock in Chile will be reported. This seeks to link the use of designs and dwelling construction technologies with climate zones.

2.1. Climate and potentialities

2.1.1. Introduction

Climate is the most important external factor that is necessary to know in order to conceive a building. The study of the climate for which a building is designed, should give the basic guidelines regarding the design and the materiality for which the product is satisfactory; this is of acceptable quality. A acceptable quality building must have the characteristics that meet its users needs; it should accommodate their physical, physiological and psychological requirements, which are the very essence of the residential building, and provide appropriate comfort and safety conditions. It must be sufficiently self-protecting, so that it has a long lifespan in order to justify the investment and, as is increasingly important, be ecological and economical in terms of energy consumption. For all these purposes, knowledge of climate and the buildings physics is of vital importance.

For the purposes of architectural design, climate is defined through five climatic factors: temperature, humidity, precipitation, wind, and solar radiation (AIA, 1984). Local variations of said factors determine basic

climatic conditions, the disadvantages and climatic advantages that should be taken into account when planning a building, which is what defines the potential for passive climate design. In other words, the basis of all energy-efficient passive design is to give an appropriate response to the disadvantages and advantages of climate. This strategy permits the limitation of facility size to and reduction of energy consumption to minimum optimal levels.

Basic climate conditions are those to which the building is exposed with greater frequency and which determine the design emphasis or strategy. The questions are: Above all, should heating, cooling and ventilation be used? The climate difficulties are those factors that worsen interior environment or affect its adequate achievement *(Burberry, P. et al 1983).* Temperature for example, can constitute a problem in hot as well as cold climates, especially if the excessive heat or cold is constant. Humidity can also be a problem if it reaches levels so high as to prevent evaporative cooling in summer (through perspiration), or produce condensation on walls in winter. Insulation or protection from climate difficulties is the basis of energy conservation, by reducing a dwelling's heating and cooling demands. On the other hand, sunlight is rarely a problem in cold climates, but can be a major difficulty in warm climates. Lastly, climatic advantages are understood to be those factors that make a positive contribution to indoor climate or energy savings. The use of these advantages is the basis of passive design and effectively substitutes the use of fuels and saves energy.

Therefore, knowledge of climate from an architectural perspective is essential. The question is: Does the choice of materials, designs and construction technologies used in the different climatic zones of the country consider the climatic conditions that predominate in a particular area or place, and the climatic disadvantages and advantages?

2.1.2. Climate zoning of housing in Chile.

Chile is located between 17° 30' south and the South Pole, primarily in the temperate and polar zones of the southern hemisphere. A smaller portion of its territory, approximately 700 km in length, is located in the inter-tropical zone, between the northern boundary and 23° 30' south.

According to the Köppen climate classification, Chile includes within its 15 regions, at least seven of the major climate subtypes: Desert climate in the northern regions; Mediterranean climate in central Chile; oceanic climate in the south; glaciers and tundra in the south of the country; humid subtropical on Easter Island and a polar climate in the Antarctic territory.

Due to its location, configuration, and geographical orientation, the country also contains a very wide range of micro-climates that makes collection of meteorological data complex and still inadequate for the purposes of architectural design. Meteorological information from many localities is derived from climate generation programs, which do not always deliver reliable information (MINVU, 2002). The majority of the information, the most important and detailed data, has been gathered for agricultural, mining and logging purposes, and concerns areas that are normally far from urban centers or areas where the bulk of the population is concentrated (Rodriguez, G. 1972).

The work on climate classification for architectural purposes in Chile has been based, in general, on information for specific purposes different from those that have been implemented in the country. To date there are two zoning projects for purposes of architectural design of official character: the first, created by Rodriguez (Rodriguez, G. 1973) in the 70s, includes 9 zones and gave origin to the Standard 1079 (INN, 2008), the first regulatory

instrument on the relationship between climate and architecture in Chile, and; a later zoning project by the Ministry of Housing and Urban Development, which was developed with the thermal regulation of buildings in the year 2000 and includes 7 zones (MINVU, 2006). The first is a subdivision that is recognized as climatic, whenever nearly all the factors that define the climate are taken into account. The Ministry of Housing project is based only on temperature, which is used to subdivide the territory on the basis of heating degree days, and is known as thermal zoning. Thermal zoning and its requirement standards induce design errors as explained in chapter 5. It is intended that this situation will be corrected through a proposal for improvement and updating, which is currently in development (MINVU, 2014)[2]

The classification of Rodriguez divides the country into nine zones. The zones are Northern Coast I; II Northern Desert; III Northern Transverse Valley; IV Central Coast; V Central Interior; VI Southern Coast; VII Southern Interior; VIII Southern Extreme and IX Andean. Of these regions, I, III, IV, V, VI, VII, are of primary importance due to high housing concentration. This zoning does not include the Chilean Antarctic Territory nor the island possessions overseas. For each of these zones, general requirements are proposed. Buildings constructed in them must meet these requirements in both design, and construction elements and materials involved in building. It includes requirements on the thermal transmittance

[2] At the beginning of 2014, the MINVU sent out for public consultation the technical standard MINVU NTM 011 "Requirements and mechanisms for accreditation for the environmental conditioning of buildings" that includes new zoning, increased thermal insulation requirements and for the first time, airtightness requirements. The standard is generated from the study "Proposal for updating Thermal Regulation, article 1.4.10 of the General Ordinance of Urbanism and Buildings", as requested by the Ministry of Housing and Urban Development from the consultant Mr. Waldo Bustamante Gómez and from the Fondef project D10 I 10 25 "Establishment of class of airtightness acceptable for buildings in Chile", whose director is the author of this thesis.

of envelopes, limits the maximum transmission by zone; establishes minimum roof pitch values by zone; gives recommendations or alleviation measures in many cases related to protection against air and ground humidity, and the sun, and solutions related to salt, among others.

Table 2.1 describes the location and most important climate characteristics of each zone. Figure 2.1 shows the corresponding territorial zoning. Table 2.2 presents the climate factors for locations representative of the zones and Table 2.3 presents a qualitative assessment scale for design purposes. These are general guidelines to characterize the basic climatic conditions of a locality and deduce the primary advantages and disadvantages of climate for passive design in a locality.

The country's climate, in its distinct zones, is strongly influenced by two mountain chains of several thousand kilometers in length, the Andes Mountains, the Coastal Mountain Range and the Pacific Ocean. These features isolate the country geographically, in that the effect of the rest of the continent on the local climate is very weak or non-existent. Most cities are built on the coast and in the narrow valley that lies between both mountain ranges. The plain occupies only one-fifth of the national territory and 90% of the population is clustered in low-lying areas below 800m above sea level, which is contrary to the situation in the rest of the Andean countries. The sea bathes a coastal area that extends from 18° to 56° south latitude, not including the Antarctic territory, in a significantly north-south direction, with a length of more than 4,200 km. The average width does not exceed 170 kms, which means only 1/25 of country's length.

The climate, in which human activity occurs, is in general smooth, due to the regulating action of the sea and the protective wall of the Cordillera of the Andes. The Humboldt Current is responsible, in large measure, for thermal

inversion, negative for the northern area and positive for the southern. This causes the theoretical temperature averages to be different compared with real data: in this way the north is colder on average 4 °C and the south warmer 2 °C. Daily fluctuations in the interior and Andean zones are extremely marked, capable of reaching 25 °C in some inhabited areas. In places with these characteristics, thermal inertia plays a very important role in passive design.

The great deal of evaporation in the Pacific Ocean produces a large amount of clouds that move toward the continent. From South to North, on reaching the coast these clouds encounter convection currents that often modify their course, especially in the northern zone. Precipitation increases markedly from north to south, influenced by the topography and regional conditions that create numerous micro-climates. However, precipitation increases broadly in relation to latitude, from rainfall of about 25 mm annually at 20° S (Iquique), to rainfall of about 4,076 mm at 48° S (San Pedro). On the other hand, moving southward, days are longer in summer and shorter in winter, which explains the fact that in summer daily solar radiation does not decrease dramatically, because the decrease in the instant value of solar radiation due to the reduced height of the sun is compensated by increased time on the horizon.

Table 2.1: Description and zone boundaries according to NCh1079.

Zona	Características Generales
1 NC	Northern Coast: Desert zone with dominant maritime climate. Extends from the Peruvian border to the Aconcagua River, occupying the coastal strip on the west side of the Coastal Mountain Range, up to where the influence of the sea is directly felt. This zone penetrates the interior in the valleys where rivers and rivenes end. Variable width reaching up to 50 km approximately.
2 ND	Northern desert: desert zone, no rain, hot, clean atmosphere with strong solar radiation. Cold nights, dry environment. Occupies the plain between the mountain ranges of the coast and the Andes, from the border with Perú to the height of Potrerillos, excludes Pueblo Hundido and Chañaral. Eastern boundary is considered to be the 3,000 m level line approximately.
3 NVT	Northern Transverse Valleys: Transitional zone, long hot summers. Micro-climates in the valleys, scant rainfall increases toward the south, strong solar radiation. Occupies the belt region and transverse valleys to the east of the NC zone excluding the Andes Mountain Range above 400 m and from Pueblo Hundido up to the Aconcagua River valley (exclude)
4 CC	Central Coast: Zone with maritime climate, short winters and significant rains. Coastal belt next to the NC zone, from the Aconcagua to the Biobío valley (excluded). Penetrates broadly in the wide valleys that end in river mouths.
5 CI	Central interior: Zone with a temperate climate, pleasant temperatures, winters from 4 to 6 months with rain and normal vegetation, frost on the rise. Central valley between the NC and the pre Andes Mountain Range below 1000 m. In the north, starts with the Aconcagua Valley and in the south reaches up to the Biobío Valley (excluded).
6 SL	Southern Coast: Zone with maritime climate and rainy. Strong winds with a westerly component. Humid, saline soil and environment. Robust vegetation. Continuation of CC zone from the Biobío to Chiloé and Puerto Montt. Variable width, penetrating through the valleys of the numerous rivers that cross it
7 SI	Southern Interior: Rainy, cold zone, with frequent frost. Short summers of 4 to 5 months. Numerous lakes and rivers. Robust vegetation. Continuation of CC zone from the Biobío (included), to the Reloncavi Inlet. Toward the east, to the Andes Mountain Range below 600m approximately.
8 SE	Southern Extreme: Cold and very rainy zone, decreasing from W to E. Especially maritime climate, strong winds, almost permanent cloud cover, very short summers. Very humid soil and environment. Made up of the canals and archipelago region from Chiloé to Tierra del Fuego. Contains a portion of mainland to the east. There are considerable climatic variations within this zone.
9 AN	Andean: Zone with dry atmosphere, large variations in temperature between day and night. Summer storms in the High Andean Plateau (north). Blizzards and snow in winter. High amount ultraviolet radiation in sunlight. Includes the pre-Andean and Andean belts above 3,000 m in altitude in the North (High Andean Plateau Zone) that gradually lowers toward the South and is lost to the South of Puerto Montt. > 900m of altitude. Considerable climatic variations occur within

Source: NCh1079.Of 2008.



Figure 1.1: Climatic zoning of Chile.

Table 2.2: Climatic factors and qualitative assessment for passive design in localities representing each climatic zone of Chile

Zona	Pendiente de cubierta, valores mínimos en %		Orientación de muros que requieren protección contra el sol	Localidad más importante	Temperatura °C				Insolación cal/cm3/día		Soleamiento horas sol/día		Humedad %		Nubosidad décimas		Precipitación mm		Vientos predom. Dir. m/s	Heladas		Nieve días/año	Salinidad		Altura m
					Media		Oscilación diaria																		
	Superf. Rugosa	Superf. Lisa			E	J	E	J	E	J	21 dic.	21 jun.	E	J	E	J	Anual	Máx 1 día		Meses	N° d/año		Atm	Suelo	
I Norte Litoral	10	5	W	Iquique	20,5	14,9	7,3	5,0	600	250	13,3	10,9	72	75	4,0	7,6	2,6	12,8	SW 3,1	No	0	0	Sí	Sí	< 500
					MA	M	B	B	F	B			A	A	M	A	B	-							
II Norte Desértico	10	5	E - W	Calama	16,9	8,0	17,6	20,2	610	340	13,5	10,5	-	36	-	-	45	-	W 8,7	May.-Oct.		0	No	Sí	> 700 <3000
					C	F	A	A	F	N			B	B	MB	MB	MB	MB							
III Norte Valle	15	8	E - W	Copiapó	20,4	11,4	16,2	15,0	620	290	13,8	10,3	61	69	-	-	24	-	W 5,1	Jun-Ago.		0	No	No	<400
					MC	F	A	M	F	N			N	A	B	B	B	-							
IV Central Litoral	20	10	W	Valparaíso	17,8	11,4	9,2	7,3	520	160	14,2	9,9	70	78	4,0	6,1	463	171	SW 6,2	0	0	0	Sí	Sí	<250
					C	F	B	B	N	B			A	MA	B	A	A	-							
V Central Interior	15	8	E - W	Santiago	20,7	7,9	17,0	11,3	570	130	14,3	9,8	52	79	1,7	5,8	367	103	SW 2,6	Jun.-Sep.	15	0,7	No	No	>100 <1000
					MC	F	A	M	F	MB			N	A	MB	MB	A	-							
VI Sur Litoral	30	15	W - N	Concepción	16,6	8,7	10,9	7,5	580	150	14,5	9,5	75	88	2,8	6,4	1338	118	SW 6,7	Jul.-Sep.	5	0	Sí	No	<200
					M	F	M	B	N	MB			A	MA	B	A	MA	174							
VII Sur Interior	30	20	W - N	Temuco	18,0	7,4	16,5	7,5	520	130	14,7	9,3	60	86	3,2	7,4	1208	137	Calma	Ene.-Dic.			No	No	>100 <700
					M	F	A	B	N	MB			A	MA	B	A	MA	-							
VIII Sur Extremo	30	25	-	Punta Arenas	11,2	2,2	8,2	4,7	490	80	16,8	7,4	68	80	6,7	5,9	416	98	W 8,2	Abr.-Oct.	52	18	Sí	No	<500
					F	MF	B	B	N	MA			A	MA	A	A	MA	-							
IX Andina	40	30	W	Potrerillos	13,7	8,5	18,6	8,3	600	300	13,7	10,4	39	61	1,5	2,4	1073	114	Calma	May.-Oct.	15	2,1	No	No	<3000 >800
					M	MF	A	M	F	B			B	A	B	M	MA	-							

Source: Created by the author with data from NCh 1079 Of.2008

Table 2.3: Qualitative appreciation scale of climatic parameters for passive design

Parámetro	Rango	Concepto
Temperatura media T (° C)	19° C < T	Muy alta-Muy caluroso (MA)
	17°C < T ≤19°C	Alta-Calurosa (AC)
	12°C < T ≤17°C	Mediana-Templado (MT)
	7°C < T ≤12°C	Baja -Frío (BF)
	T < 7° C	Muy baja-Muy frío (MB)
Oscilación diaria OD (°C)	19° C < OD	Alta (A)
	9°C ≤ OD ≤ 19°C	Media (M)
	OD < 9 ° C	Baja (B)
Insolación I (Wh/m día)	6.397≤1	Fuerte (F)
	2.908 ≤ I < 6.398	Normal (N)
	1.745 ≤ I < 2.908	Baja (B)
	I < 1.745	Muy Baja (MB)

Parámetro	Rango	Concepto
Velocidad viento V (m/s)	V≤2,0	Muy Baja (MB)
	2,0<V≤3,0	Baja (B)
	3,0<V≤5,0	Normal (N)
	5,0<V≤7,5	Alta (A)
	7,5<V	Muy alta (MA)
Humedad relativa HR (%)	80% < HR	Muy alta (MA)
	65%≤HR<80	Alta (A)
	45%≤HR<65%	Normal (N)
	35%≤HR<45%	Baja (B)
	HR<35%	Muy Baja (MB)
Precipitación anual PA (mmcda)	1.200<PA	Muy alta (MA)
	600<PA<1200	Alta (A)
	200<PA<600	Normal (N)
	50<PA<200	Baja (B)
	PA<50	Muy Baja (MB)

Source: Created by the author with data from NCh1079 Of 2008

2.1.3. Climatic characteristics of typical cities

2.1.3.1. The climate of Antofagasta and its potentiality

The city of Antofagasta is located on the coast, at 23°38'39 S latitude, 70°24 '39 W longitude, and has average elevation of 40 meters above sea level. It has a cloudy, coastal desert climate, with a saline atmosphere and soils, and little to no vegetation. These conditions are manifest up to 20 kilometers into the interior. Its main characteristics are the absence of rainfall (1.7 mm annually); marked, partial morning cloudiness; high relative humidity (78%); high air temperatures (averages of 20.0 ºC in January and 13.4 in June); low thermal fluctuations (7.2 °C in January and 6.3 °C in June); strong levels of solar radiation in summer (780.0 MJ/m² month) and normal in winter (330.0 MJ/m² month); and prevailing winds from the South at 4.5 m/s. Temperature regulation is due to its proximity to the sea, to the participation of the Humboldt Current and the presence of the semi-permanent South Pacific

anticyclone, which generates winds from the south and from the southwest. All this translates to mild, stable temperatures during most of the year.

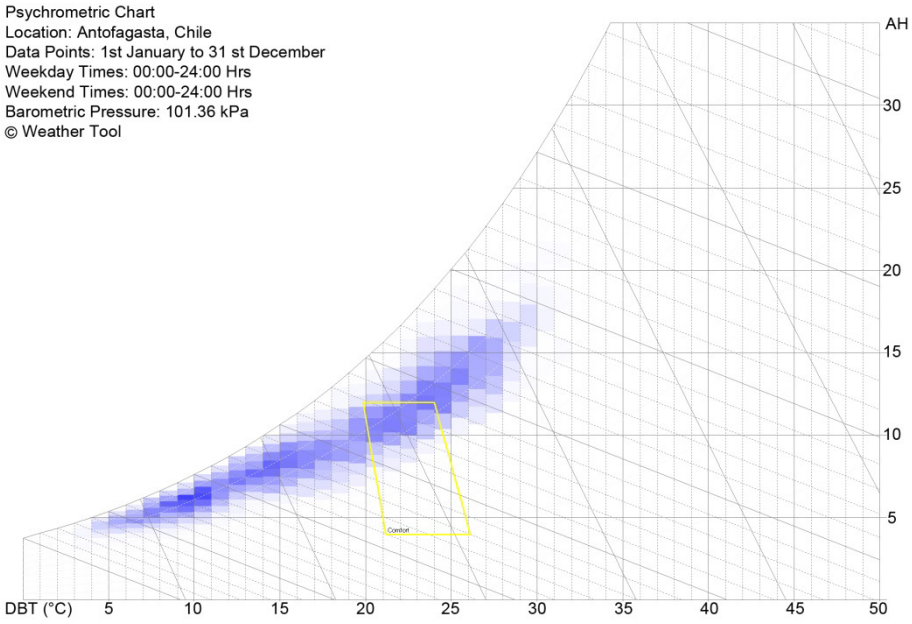


Figure 2.2: Exterior environmental climate conditions city of Antofagasta.
Source: WeatherTool based on a file extracted from Meteonorm

As can be seen, the basic climatic conditions that determine the emphasis of the strategy in Antofagasta are solar radiation and high temperatures, which determine that, above all, the main needs are cooling and ventilation. The demand for heating should be low and easily passively controllable. The inconveniences that most affect the interior climate are solar radiation and humidity in the atmosphere. The advantages include wind speeds and air temperatures appropriate for cooling thermal mass by night ventilation. The best energy and environmental performances are related to envelopes with low thermal insulation (U: 2 to 3 W/m² K) and airtightness (n50 8 to 15 (1/h); preferred southern orientation and high solar protection in a western direction (solar factors in the 0.4-0.6 range). Its orientation to the south also

generates greater lighting demands. However, the reduction in cooling demand can compensate very well for the greatest lighting needs.

2.1.3.2. The climate of Santiago and its potentiality

Santiago is located at 33°26' S and 70°41' W, at an average altitude of 520 meters. It is within the Central Interior zone. The climate associated with this zone is temperate with winter rains and a prolonged dry season. It is characterized by: rainfall concentrated in the winter and a dry season from 7 to 8 months when precipitation is less than 40mm (310mm per year approximately), and high average temperatures during the summer (20.9 ºC) and relatively low in winter (8.1 ºC). The city's continental nature increases the thermal fluctuations, which are considerable daily as well as yearly (16.7 ºC in January and 11.0 °C in June). Solar radiation is intense in the summer (715.1 MJ/m² month), especially in the northwest, and is low in the winter (142.3 MJ/m² month). Wind speed is in the range of 2.5 - 3.0 m/s in a prevailing SSE direction; the relative humidity in the air is in normal to low ranges in summer (57%), and high to very high ranges in winter (84%).

The basic climatic conditions that determine the emphasis of the strategy in Santiago are the low temperatures in winter. However, the climate is moderate and the solar radiation and temperatures in much of the year necessitate the consideration of a flexible design. The disadvantages that mainly affect indoor climate are the low outdoor temperatures, high solar radiation and low air velocities almost year round. Low wind pressures in summer generate heat islands, and in winter, along with bad heating practices, serious air pollution events. The advantages are found in the thermal oscillation, which may feasibly be taken advantage of with adequate management of thermal mass. The best environmental and energy

performances are related to envelopes with high thermal insulation (U: 0.5 to 1.0 W/m² K) that are relatively airtight (n50: 4 to 6 1/h); have a preferably northern orientation and high solar protection in an E-W direction (solar factors in the range of 0.4-0.6).

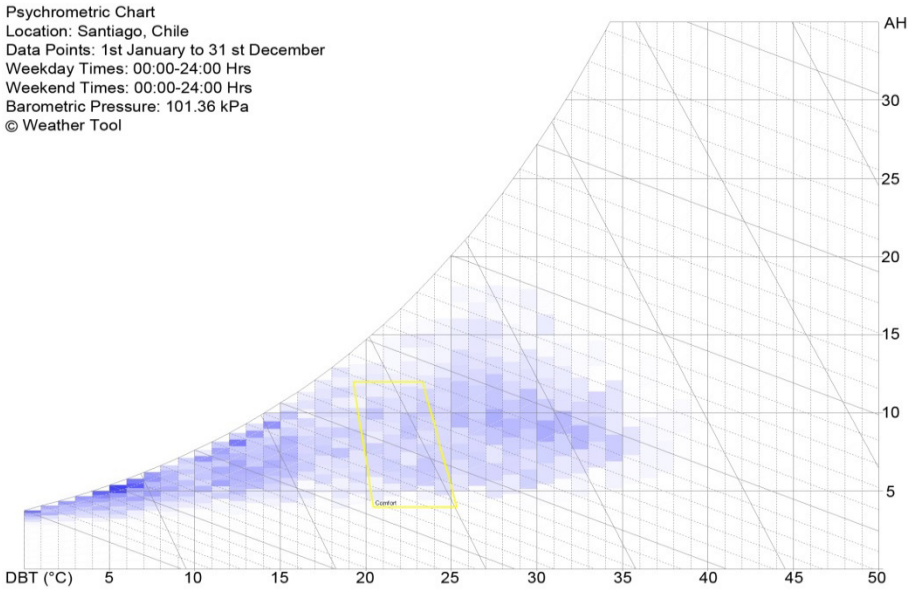


Figure 2.3: Exterior environmental climate conditions city of Santiago
Source: WeatherTool based on a file extracted from Meteonorm

2.1.3.3. The climate of Concepción

Concepción is located at 36°47' S and 73°7' W, at an average of 15 meters above sea level. It is considered to be within the Southern Coast Zone according to the NCh 1079 classification. The climate of this locality is warm and temperate and strongly influenced by its proximity to the sea, which moderates the thermal oscillations both daily and annually. The local climate is categorized as Mediterranean transition: a mix between a typical Mediterranean climate and a typical temperate coastal climate. Its dominant characteristics are: rainy (1,338 mmcda annually) moderately cold winters, mild summers with very occasional periods of extreme temperatures

(averages of 8.5 °C in June and 16.3 ºC in January), and high ambient humidity throughout the year (80%). Daily temperature fluctuations are low, but increase slightly in summer (7.5 ºC in January and 10.9 °C in June). Solar radiation in summer is strong (71.8 MJ/m² month) and low in winter (142.1 MJ/m² month). Winds are strong, irregular, and predominantly southwesterly, with an annual average of 4.9 m/s.

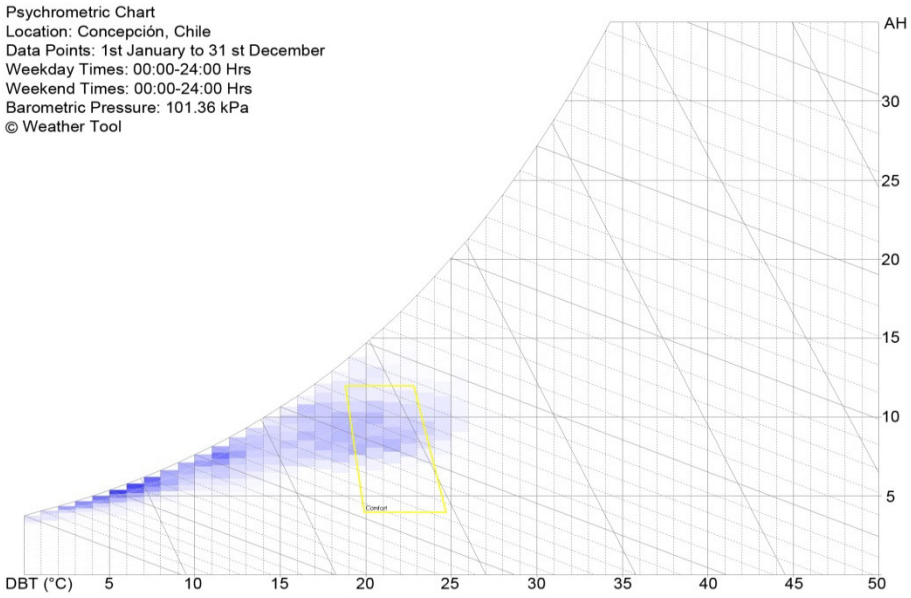


Figure 2.4: Exterior environmental climate conditions city of Concepción
Source: WeatherTool based on a file extracted from Meteonorm

The combination of northern winds and precipitation is common in this zone. The soil and the environment are saline and humid, and the vegetation is robust. Basic climatic conditions that determine the emphasis of the strategy in Concepción are the low temperatures in winter and high humidity. However, as in the city of Santiago, the climate is still moderate so that it also requires a type of flexible design. The disadvantages that mainly affect indoor climate are the low exterior temperatures, and especially the high ambient humidity in winter, which tends to generate serious

condensation problems. The high solar radiation in summer necessitates protecting light structures from overheating. The advantages are found in summer wind velocities, which offer excellent potential for ventilation and cooling. The best environmental and energy performances are related to envelopes with high thermal insulation (U: 0.5 -1.0 W/ m² K), that are relatively airtight (n50: 4 To 6 1/h), have a preferred northern orientation and high solar protection in a N-W direction (solar factors in the range of 0.4-0.6).

2.1.3.4. The climate of Punta Arenas

Punta Arenas is located at 53° 8' S, 70° 53' W, at an average of only 3 meters above sea level. The climate associated with this city is called continental trans-Andean with steppe degeneration. It is characterized by the predominance of cold temperatures, high humidity and moderate precipitation distributed evenly throughout the year, without exceeding 300mm of rainfall annually. The climate is particularly maritime, characterized by cold to very cold temperatures (averages of 2.2 ºC in June and 11.2 ºC in January). Daily temperature fluctuation is low in both summer and winter. The higher areas frequently experience snow and frost, especially towards the south of the zone, where strong winds are also present. In general, summers are short and cloud cover nearly permanent. The prevailing winds are southerly and westerly (annual average speeds of 7.9 m/s). Solar radiation is moderate in summer (575.3 MJ/m² month) and very low in winter (47.1 MJ/m² month). The soil and environment are very humid and vegetation is robust.

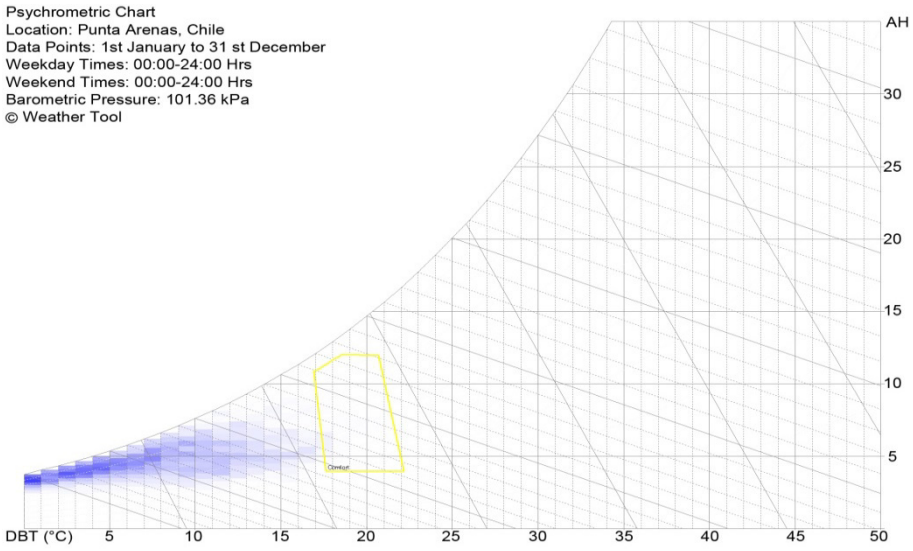


Figure 2.5: Exterior environmental climate conditions city of Punta Arenas
Source: WeatherTool based on a file extracted from Meteonorm

It is claimed, the basic climatic conditions that determine the emphasis of the strategy in Punta Arenas, are relatively low outdoor temperatures in winter and high wind speeds, which determine heating to be a clear, dominant need. The disadvantages that mainly affect indoor climate are the low exterior temperatures and high wind pressure, which increase heat losses due to convection. The advantages are also found in the wind speeds and the thermal differential, which cater perfectly and naturally to ventilation requirements for hygiene and health purposes. The best energy and environmental performances are related to envelopes with very high thermal insulation (U: less than 0.5 W/m² K), high airtightness (n50: less than 3 1/h), a preferably northern orientation, and protection against the action of the wind in windows and doors.

2.1.3.5. Potential for natural ventilation

The strategies for resolving ventilation in residential buildings are quite varied. The choice will always be subject to the economic and technological means available, the building's design and environmental conditions, and the potential of the locality's air to ventilate and cool, which can be seen by observing climate data. In Table 2.4, climate data are presented with their qualitative assessments in order to evaluate the potential of the local climate.

Natural ventilation strategies based on cross ventilation and caused by wind pressure offer their greatest potential in localities with average wind speeds above 3m/s (Wouters, P. 2010, Wouters P. et al 2008). The same air can serve to cool in summer when average temperatures are under 17 °C (Medium Temperate) and will be more useful the lower this number is. Thus, strategies based on convection ventilation by thermal draft show better performance in those localities with more extreme average temperatures, where the thermal differential is higher, in special zones with low and very low average temperatures in winter. Lower thermal differentials, less than 10 ºC, require the use of large areas of openings and/or Stack integrated into the design of considerable heights.

Table 2.4 presents climate data from some localities in Chile with recommendations for ventilation and/or cooling strategies adequate to the characteristics of the natural environment. There is always a strategy that is technically more appropriate or convenient than another. In practice these are combined, and it is desirable that this should be so, considering the dynamics and yearly evolution of wind pressures and thermal differentials that determine the "mobilizing force" of the air.

The city of Concepción, with an annual average wind speed of 4.9 m/s, offers a very good opportunity for cross ventilation throughout the year. The average temperature during the summer period slightly exceeds 15 ºC, which is why ventilation could serve very well for cooling purposes. In winter, thermal differentials also enable increased ventilation from thermal effects, which may be important if there is a stack effect in the building.

Table 2.4: Background on the potential of the natural environment of the localities to cool and ventilate: High (A); Medium (M) and Low (B) and most recommended principles of ventilation: stack effect (SE); wind effect (WE) and cooling (CO).

Ciudad Estación	Parámetros Climáticos	Enero	Junio	Media Anual	Pot. Ventilación		
					EV	ES	E
Iquique Diego Aracena	T. media max. °C	24,9	19,0	21,3	M	B	B
	T. media mín. °C	17,6	13,5	15,1			
	T. media, °C	21,1	15,9	18,0			
	Dir. y Vel.media, m/s	SW 3,1	SW 3,1	SW 3,1			
	Rad.Glob. mes,MJ/m²	727,8	313,6	6240,4			
Santiago Quinta Normal	T. media max., °C	29,7	15,2	22,5	B	M	B
	T. media mínima, °C	13,0	4,3	8,3			
	T. media, °C	20,9	8,5	14,4			
	Dir. y Vel.media, m/s	SW 2,6	Calma	SW 2,1			
	Rad.Glob. mes,MJ/m²	715,1	142,3	5062,0			
Concepción Carriel Sur	T. media max., °C	22,8	13,4	17,7	A	A	A
	T. media mínima, °C	10,5	6,2	7,7			
	T. media, °C	16,3	9,2	12,2			
	Dir. y Vel.media, m/s	SW 7,7	N 8,2	SW 6,7			
	Rad.Glob. mes,MJ/m²	761,8	142,1	5422,9			
Punta Arenas Pdte. Ibañez	T. media max., °C	14,7	4,2	9,7	A	A	A
	T. media mínima, °C	6,5	-0,7	2,8			
	T. media, °C	10,5	1,5	5,9			
	Dir. y Vel.media, m/s	W 9,3	W 6,7	W 8,2			
	Rad.Glob. mes,MJ/m²	575,3	47,1	3634,9			

Source: Created by the author with data from NCh1079 Of.2008

The city of Santiago, with an annual average wind speed of 2.1m/s, on the limit of what is considered "Calm", offers very low potential for wind effect ventilation throughout the year. Opportunities for thermal effect ventilation are better in winter. In this case, it is necessary to use stack effect with

relatively large heights (for practical use, above 25m with thermal differentials of 10 ºC to obtain pressures of 10Pa).

2.2. Residential Buildings

The market for residential construction is currently one of the most dynamic and demanding in the Chilean economy. The industry has needed to improve its productivity indicators, on the one hand, to meet the historical deficit and replenish the homes that were destroyed by the earthquake and tsunami of 2010 and, on the other hand, improve its quality indicators, to comply with new building standards from the Ministry of Housing and Urban Development. In general new provisions to regulate the energy efficiency of housing, among others, have forced the industry to develop some levels of innovation, and technological changes, both in materials and building systems and processes, and in organizational and management systems, in order to respond to these new quality requirements emerging in Chile. All of these changes have gradually been reflected in housing stock in Chile.

2.2.1. Intention of residential construction 2011

In the year 2011, the number of new dwellings totaled 151,071 units, equal to 10,431,880 m2 of floor area. With respect to 2010, there is a 57.3% increase in units and a variation of 60.0% in floor area. This important growth can be explained primarily by the need to replace homes destroyed as a result of the earthquake and tsunami of 2010. The source of information is building permits authorized monthly in 2011 by the Municipalities of Chile, which were collected and processed by the National Statistics Institute of Chile (INE, 2012).

28.3% of the floor area of housing built is concentrated in the Metropolitan Region, where 35.5% of the national population resides. Of this total, 36.9% corresponds to apartments and the rest to houses. Apartment construction has shown sustained growth in recent years; in 2001, it represented only 21.4% of total construction. Higher land costs, housing densification needs, and specific market conditions explain these changes in structure.

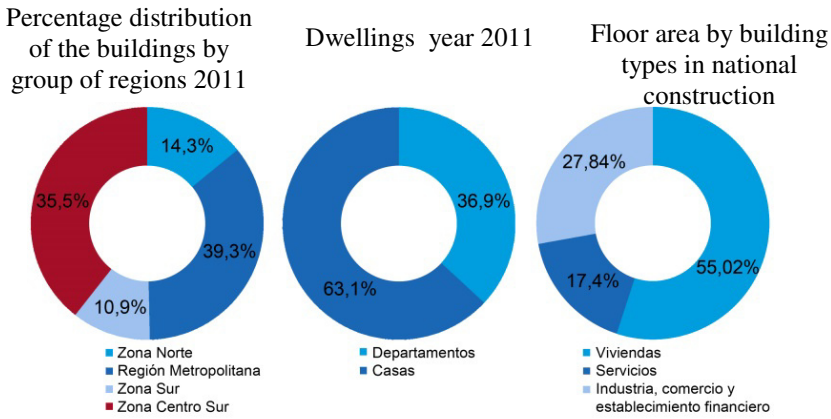


Figure 2.6: Distribution by sector, territory and type of housing authorized in 2011
Source: Created by the author with data from INE

In Table 2.5 shows the distribution of types of housing in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas, cities that for purposes of analysis shall be construed as hereinafter representative areas of the north, central, south and south end respectively.

Table 2.5: Percentage of floor area by housing type in Antofagasta, Santiago, Concepción and Punta Arenas

Destino	Antofagasta	Santiago	Concepción	Punta Arenas
Casa aislada	11,7%	19,2%	25,2%	43,1%
Casa continua	7,5%	0,6%	1,7%	1,0%
Casa pareada	2,6%	3,6%	21,6%	47,4%
Departamentos	78,1%	76,6%	51,5%	8,5%

Source: Created by the author with data from INE

As can be observed, the construction of dwellings increases towards the south. In Antofagasta and Santiago, the building of apartment high-rises is favored. In the case of Concepción, the number of housing units is divided equally between houses and apartments. The size of residential constructions changes greatly between large cities and lesser towns where mainly detached dwellings are built.

2.2.2. Predominant materiality in the housing stock

In accordance with the classification of the General Ordinance of Constructions, under the designation predominant material in walls, official statistics identify the structure or building system used. The wall identifies the structural support element and load transmitter in many building systems. Considering that in some cases a combination of two or more systems is used, normally the predominant element is identified in the first place.

Table 2.7 shows the use of different predominant materials in the building systems used in the year 2011. Traditional heavy construction in concrete prevails. This represents 36.8% and is mainly used in apartments. Seven generic types of buildings were used in 94.2% of housing stock authorized in the year 2011.

Table 2.6: Participation of the different materials predominantly in walls in the various building systems used in the year 2011 at the national level

Materialidad predominante en muros	Edificación total	Número	Superficie	
			m^2	%
Hormigón	7.012.075	54.640	3.841.653	36,8%
Ladrillo	4.112.918	47.655	3.389.983	32,5%
Madera	2.341.414	28.954	1.819.052	17,4%
Bloque cemento	470.225	6.790	425.586	4,1%
Paneles	322.888	3.462	232.206	2,2%
Metal panel preformado	1.776.007	1.128	110.826	1,1%
Adobe	19.060	80	11.776	0,1%
Otros	757.062	8.362	600.806	5,8%

Source: Created by the author with data from INE.

2.2.3. Distribution of materiality and systems by thermal zone and province

Figure 2.7, shows how different groups of materials are linked to the thermal zone in which they are used. The use of brick masonry and concrete in the basic, conventional way is practically confined to the first thermal zones as can be seen, less demanding, which appears to be very logical. In the zones with the highest thermal requirements, those in the south of the country and in the Andean zone that runs from the north to south of Chile, combined systems and light technologies that exploit thermal attributes are preferentially presented. They have been gradually introduced into these market territories, displacing the traditional heavy construction in brick masonry and concrete.

Figure 2.8 shows the main combinations of building systems, associated with the materialities of concrete, ceramic brick, wood, panels, and lightweight structures, currently on the market for residential construction. With the purpose of improving the productivity of the works and adjusting the supply of real estate to the new requirements, in the field of thermal protection, which has been regulated since the year 2007, acoustics since 2005, and fire resistance since 1990, the industry has had to make changes to different degrees. These changes that are conceptually typified as innovations, include new and/or to a lesser degree adapted systems, and existing systems that should be improved to continue participating in the market.

Construction in concrete and masonry, which until just prior to the thermal regulations was undertaken virtually in the same manner throughout the national territory, was obliged to supplement its thermo-isolating capacity in order to be used from thermal zones 3 to 7. In this way, a number of

complements arose as thermal reinforcements, applied to the interior or exterior to achieve the required thermal standards in these zones. To this end, various systems are used. Many of them are of the EIFS (External Insulation & Finish System) variety, shells that are achieved on the basis of different materials and technologies. The most common involve the use of fastening elements between the wall and the insulating material, generally adhesive pastes, a protective mesh and an exterior stucco over the insulating material. In the cases that the reinforcement requirement is lower, insulating mortars up to 3 cm in thickness are used. In this way, thermal improvements are achieved for brick masonry, for example, which do not exceed 10%.

In the year 2011, 61.5% of housing constructions used only brick as their predominant material, and the rest, brick combined with other construction systems. There are basically two kinds of complements: as thermal reinforcements for walls, or in two-story buildings where the second level is typically a lightweight structure of conventional wood or other systems based on different kinds of panels. Brick masonry is the system that is most frequently combined with other technologies and materials, as illustrated in Figure 2.8.

Another level of changes has been produced by means of innovations that normally result from R & D work. In this category are self supporting systems like reinforced concrete and HIT (concrete, technological innovation in Spanish), and systems based on wood panels, which are the result of joint projects between CITEC UBB and several local businesses (CITEC UBB 1995, 2002, 2003, 2006). These include new ceramic bricks (Bobadilla A. and Others 2009), the Metalcon System introduced by the Business CINTAC, SIP (Structural Insulated Board) developed in the United States and introduced and adapted to local conditions by several businesses, among others. In general, prefabricated systems that arose at the beginning of the

first decade of the 21st century to resolve problems of productivity and quality in residential buildings only began to be incorporated more regularly in Chile in 2007, when the thermal regulation entered into force. Nevertheless, in Chile they do not exceed 15% of the housing construction market at present. Some of these solutions are presented in Figure 2.9. A more complete description of these technologies, in particular their technical performance, is presented in chapter 4 of this thesis.

Building statistics show that construction in masonry and concrete is gradually losing competitiveness. In zones 3 to 7, walls of masonry and traditional concrete must incorporate thermal reinforcements, which mean higher costs. This situation clearly favors the use of light, industrialized systems such as Metalcon, SIP, and others. Today, construction with wood, panels, and other technologies that exploit their thermal attributes as differentiating advantages, represents 17.4% of the market in contrast to 13.5% in 2000. This progress does not seem important, considering the improved regulatory scenario which was opened in the last decade for the progress of this type of construction, whose structural advantages were again demonstrated during the earthquake of 2010. At present, light construction and other technologies that exploit their attributes as thermal differentiating advantages, occupies 27% of the market in the south central zone (zones 3 and 4), and 78.6% in the south and Andean zones (zones 5, 6 and 7).

The distribution of materiality by thermal zone has a certain logic in general terms. In the north, in hot weather zones, heavy construction in concrete, block, and masonry prevail exclusively. These kinds of construction decline progressively, especially concrete construction, in the temperate and cold zones in the center and south of the country. See Figure 2.7. From the central zone to the south begins the predominance of timber construction and light construction in general, with its better thermal insulation properties.

However, heavy construction in brick masonry and blocks persists in lower percentages.

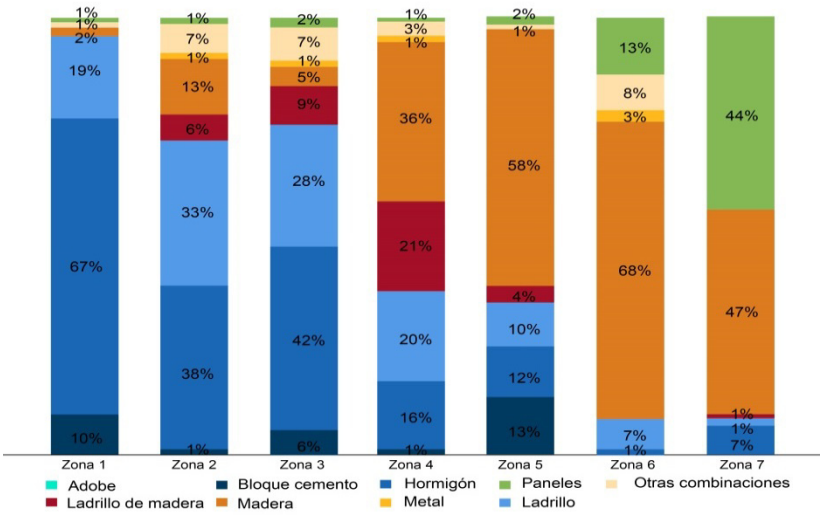


Figure 2.7: Representative percentages of materialities by thermal zone.
Source: created by the author with data from INE

Nonetheless, these strategies are not properly adjusted; lightweight timber construction and similar systems are often used without appropriately complementing mass, and in Chile, the airtightness of this type of construction is very bad[3]. Mass is passively useful in many localities of the southern interior zones and extreme south, with average oscillations above 10ºC, and strategically does not tend to be used. In addition, the energy benefits of better thermal insulation in the light systems are severely affected by the high air permeability of this type of construction. Thus, energy losses caused by infiltration surpass losses from transmission in light construction in the south of the country. The heavy constructions built in the south of the

[3] The baseline study of air leakage in Chile, undertaken in the context of Fondef project D10 I 1025, found that the average airtightness in timber construction is around 25 1/h, around 9 1/h in concrete construction, and 12.9 1/h in the housing stock.

country incorporate minimal insulating reinforcements, only to meet regulations, which clearly have low required standards.

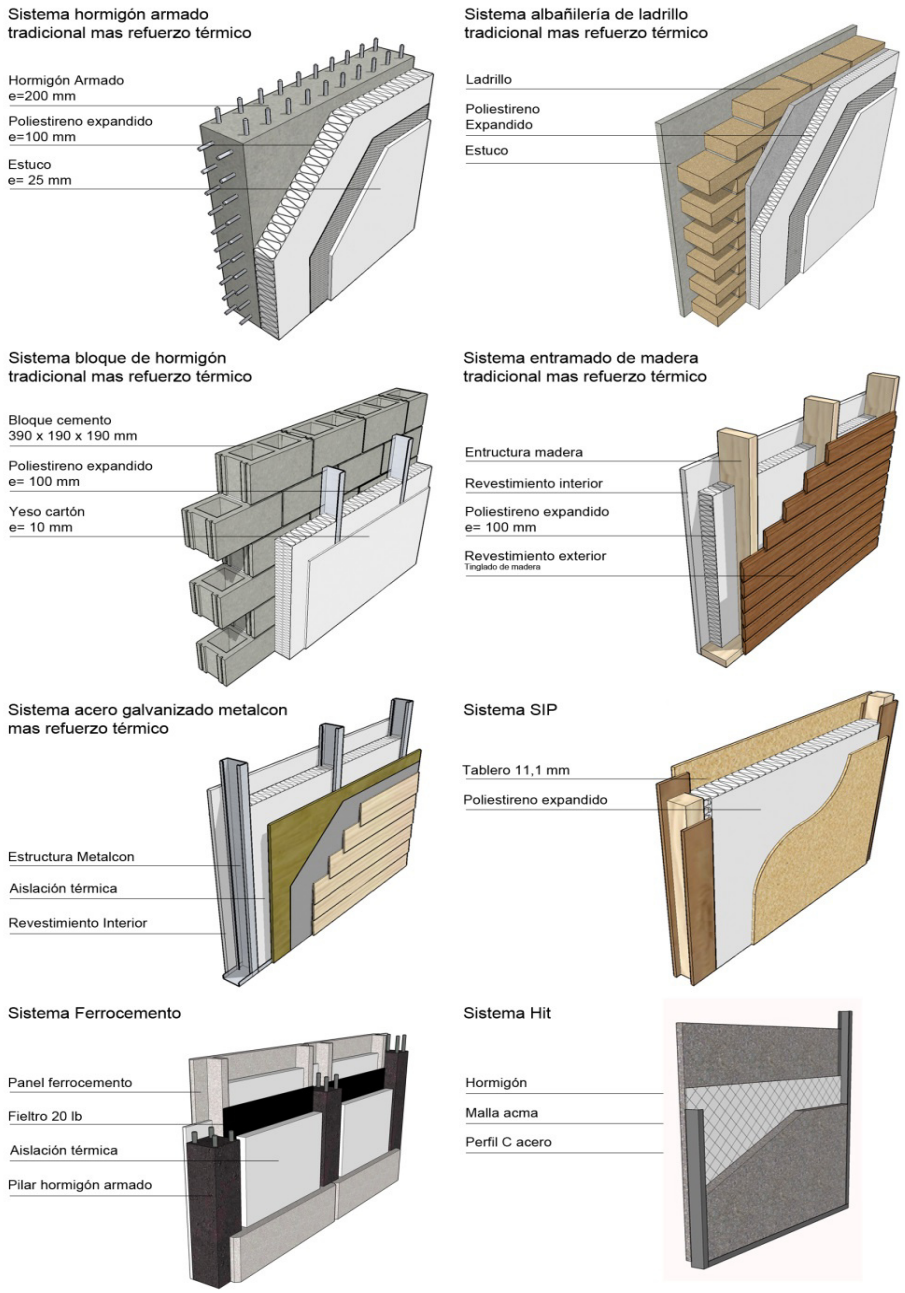


Figure 2.8: Different technological solutions for envelopes on the domestic market. Source: Created by the author

The use of materials and construction systems by thermal zone has only a relative logic. However, the disaggregation at that level obscures what happens at the provincial level. It is well known that many cities in the same zone have very different climatic characteristics, which leads to errors and affects the development of quality judgments. Figure 2.10 shows some characteristics of the housing stock from the year 2011 in some cities of Chile.

In the city of Antofagasta, 80% of the dwellings built in 2011 were detached, concrete homes and concrete buildings. In Santiago, three typologies can be identified that represent 70% of construction: concrete buildings of varying levels; two-story, detached, concrete houses; and two-story, detached, brick houses. 10% is made up of approximately twenty other construction systems. Concepción presents a greater variety of typologies. 70% of dwellings are two-story, detached and semi-detached houses with the first floor of brick and the second of wood. Concrete is used in homes and apartment buildings. Wood is employed in one and two floors, as well as other combinations that incorporate blocks and panels. In Punta Arenas, there is a preference for detached one- and two-story homes of timber materiality, concrete in dwellings and apartment buildings, and other materialities based on reinforced concrete panels and blocks.

The cluster analysis shows that compactness tends to be higher in northern zone and lower in the southern zone, where more isolated and less dense construction prevails, which is contradictory. Light construction dominates in the zones with more extreme levels of thermal protection, which naturally tend to greatly exceed obligatory levels but are highly permeable to air.

Heavy construction with blocks, concrete and brick masonries is present at significant levels in the zones with heating demands. Normally, this type of

construction is modified with thermal reinforcements, some very minor, in order to strictly comply with regulatory requirements that are known to be low. For this reason, in the end this type of solution is not appropriate in many cases. For example, in thermal zone 4 transmittances of 1.7 W/m² K (regulatory limit) are achieved in simple, 14 cm thick brick masonry walls by incorporating 10mm gypsum board as a thermal reinforcement, in a zone with minimum insulation requirements in the range of 0.6 -1.0 W/m²K. Practices of this nature explain the normally high energy demands of housing stock in Chile.

The most common solution in the south central zone is construction in masonry of two floors, the first of masonry and the second of different light materialities. The most common are traditional systems based on wood, wood paneling and the Metalcon system. The last option has a structure of metallic elements that generate thermal bridges, which are not normally corrected and produce condensation problems.

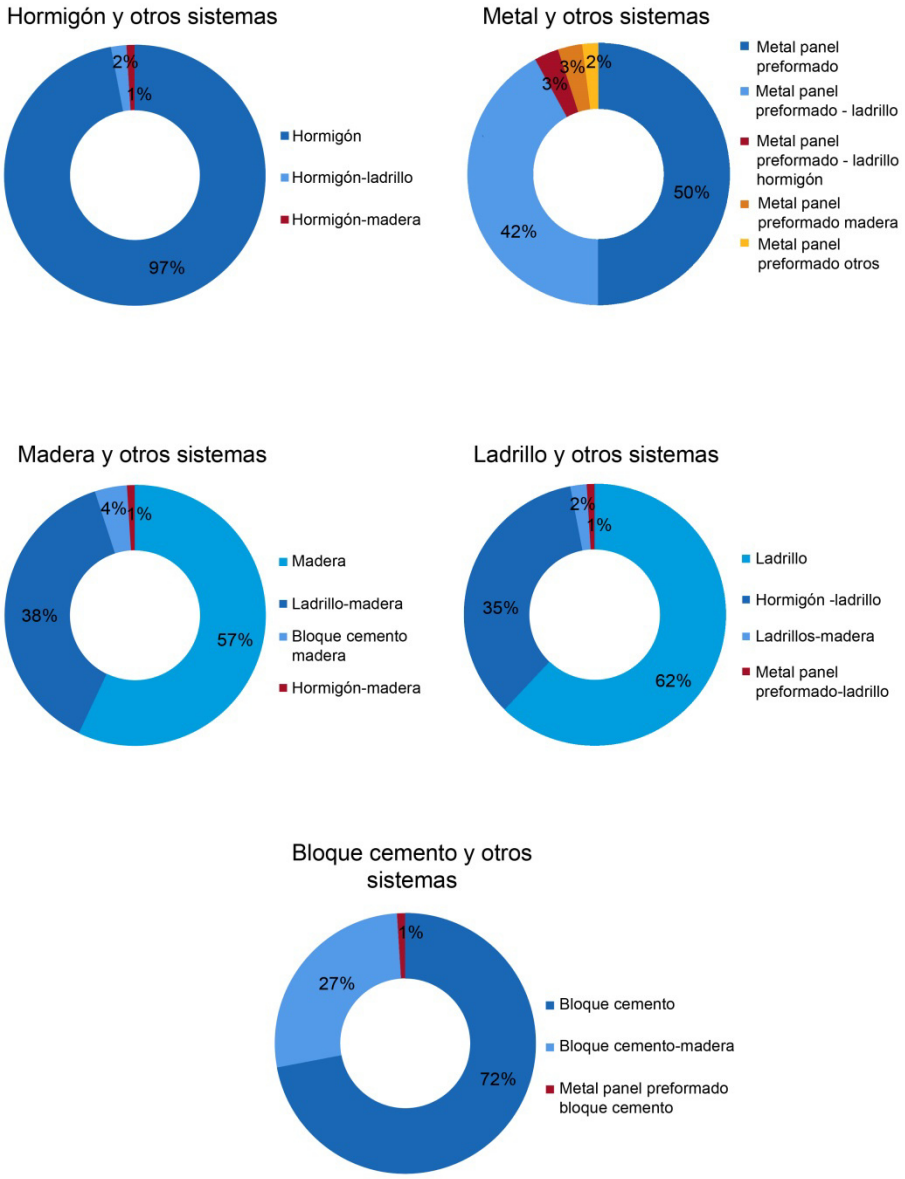


Figure 2.9: Percentage distribution of combinations of construction systems used to build dwellings in Chile, 2011.
Source: Created by the author with INE data

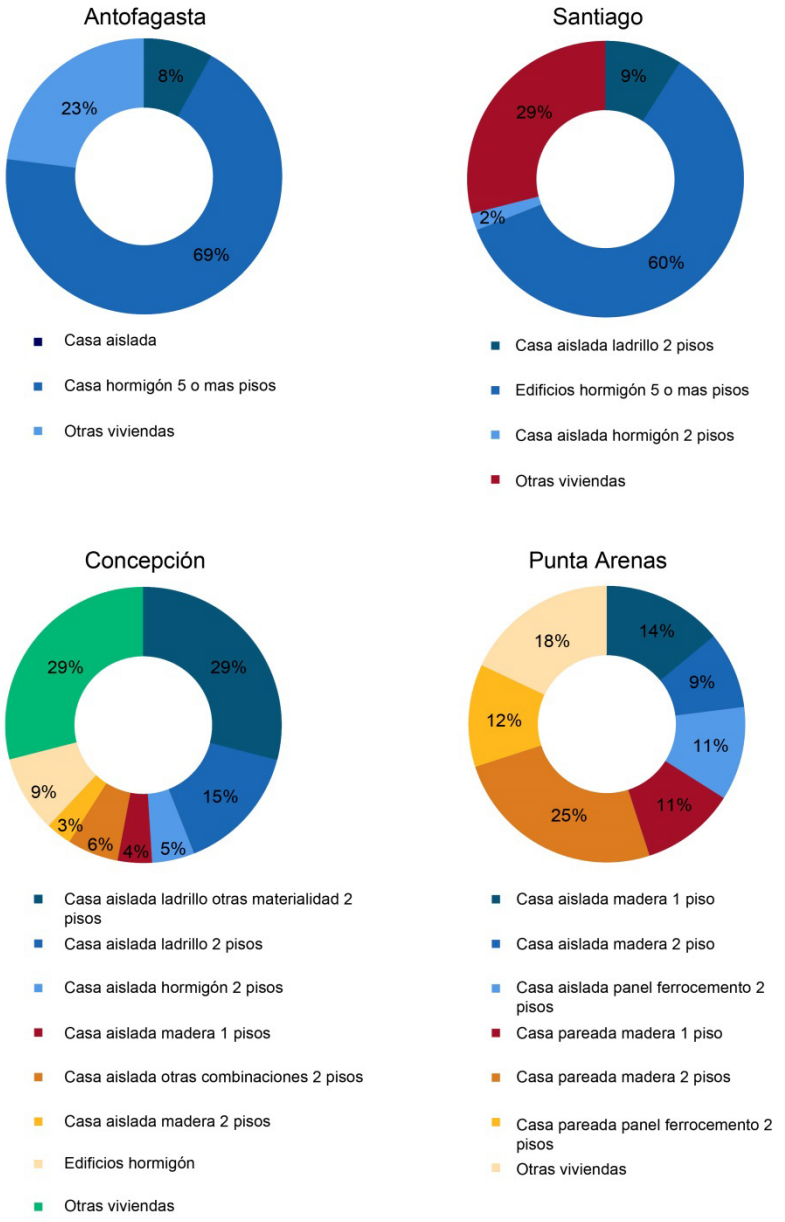


Figure 2.10: Percentage distribution of materiality predominant in walls in residential buildings of Antofagasta, Santiago, Concepción, Punta Arenas, 2011. Source: Created by the author with data from INE

2.3. Chapter 2 Conclusions

Chile is located between 17° 30' S and the South Pole. Its mainland covers a long and narrow strip of land on the west coast of the Southern Cone that extends over 4,270 km between the Andes Mountain Range and the Pacific Ocean. It reaches a maximum width of 445 km at 52° 21' S, at the Strait of Magellan, and a minimum width of 90 km at 31° 37' S, between Punta Amolanas and Casa de Piedra Pass. Due to its location, configuration, and geographical orientation, it presents a very wide range of climates and micro-climates, which makes the relationship between climate and architecture very complex.

The residential construction industry is one of the most active in the Chilean economy. The market offers an important number of technological solutions for materials, elements, construction systems, and dwellings, which compare very well with the offer of a decade ago. The light, more industrialized systems, allegedly with better thermal attributes, have gradually displaced traditional, heavy, manual construction. Prefabricated systems that arose at the beginning of the first decade of the 21st century to resolve productivity and quality issues in residential buildings begin to be incorporated with greater frequency in Chile only in the year 2007, when thermal regulation comes into force. The impact of these changes on the energy and environmental improvement of housing stock in Chile is unknown.

Building type, in terms of materiality and design does not always fit the characteristics of the climate. This is most noticeable in interior localities in the south center zone, where low outdoor temperatures and daily and seasonal fluctuations are basic climatic conditions. In these zones, light constructions without complementing thermal mass or heavy constructions with insufficient levels of thermal insulation are used intensively. These

abnormalities cause overheating in the lighter buildings, and excessive cold in the heavier constructions. In many cases, these typical problems severely affect indoor climate in these zones.

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3.0. DIAGNOSTIC OF ENERGY QUALITY

This chapter is devoted to the diagnosis of energy quality of the construction that the Chilean market offers for residential use, and to the determination of gaps in quality. It is divided into three parts:

The first part presents the work carried out to determine the energy quality baseline of the current housing supply in Chile. This is the first time that such work has used the real airtightness properties of new housing stock. The second part presents a method developed by this author to determine optimal levels of energy demand for the housing stock in different provinces of Chile, which by definition in this thesis, are assumed to be optimal energy reference levels. The third part addresses the gaps in quality by type of construction, thermal zone and country, which result from comparing the current quality levels of the housing stock with the optimal reference levels. Finally, a set of hypotheses of causes that explain the gaps is presented, on which remedial actions would have to be carried out through the plans and actions proposed in chapter 7.

3.1. Determination of the energy quality baseline

3.1.1. Methodological aspects

The first measurement or baseline reflects the state, as a starting point, of a population or reality subject to study that is intended to be modified (BID, 1997). It serves to define the initial state and, mainly, as a reference for appreciating progress and assessing the impacts of measures conducive to the modification of the initial state. The use of this technique was consulted to measure quality gaps and to establish references to evaluate policies and

programs of energy and environmental improvement of the housing stock, which are proposed as part of this thesis.

Knowing the baseline of the energy quality of housing offered by the market, in the current state of knowledge of building in Chile, posed various challenges. The first, and most important, was knowing the airtightness characteristics in the new building stock, an unknown characteristic normally underestimated in energy demand studies of buildings in Chile.[4]

Below, the main constituents of the methodology used to establish the energy quality baseline of the current supply of housing in Chile are explained.

3.1.1.1. Design and sample size

The target population is all those dwellings with building permits requested in 2011, distributed throughout the 54 provinces of Chile. This includes a universe of 151,071 housing units, which have a combined floor area of 10,431,888 m², whose main characteristics are presented in chapter 2. In this universe, the units of observation and sample for the energy quality study are the types of building present in each province that total 80% of the surface area that was planned to be built that year. For these purposes, sampling is carried out based on information collected directly from the ACCESS database, which is used to create construction statistics in Chile (INE, 2012).

[4] To calculate the energy demands of buildings and to give them an energy rating, a standard infiltration value is often used in Chile in the absence of reliable information. This value is normalized by default to 1 (1/h), independent of the type of construction, geographical location and period of the year. This assumes the same airtightness for all the buildings in Chile and the same energy losses due to infiltration for all buildings in the same locality. This criteria makes it impossible to objectively know and differentiate the capacity that buildings have to limit energy demand, which is the objective of the thesis in this phase.

The typologies are defined in terms of their participation in the target population and differentiating features relevant to the purpose of diagnosing energy quality. These characteristics or strata with their levels are shown in Table 3.1.

The combination of factors and participation criteria established the existence of 20 distinct types of building present in the 54 provinces. Table 3.2 shows the building typologies that add up to at least 80% of the surface area registered in 2011 in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas. Appendix 1 presents the territorial distribution of systems in the 54 provinces of Chile.

Table 3.2 presents the building types with average area.

Table 3.1: Characteristics and differential factors of sample subject to study

Materialidad de muros	Hormigón, ladrillo, bloque de hormigón, madera, ferrocemento, otras combinaciones (SIP, Metalcom, paneles de madera)
Agrupamiento	construcción aislada, pareada o continua
Tipo construcción	vivienda y departamento
Número de pisos	Uno, dos pisos, departamento

Source: Created by the author with data from INE

Table 3.2: Typologies of building systems that represent more than 80% of the dwellings registered in 2011 in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas

Tipologías presentes en cada ciudad						
Antofagasta: Lat. -23.63°, Long: -70.4	T6	T7				
Concepción: Lat.:-36.77°, Long: -73.06°	T3	T6	T7	T11	T12	T17
Santiago: Lat. -33.43°, Long: -70.65	T3	T6	T7			
Punta Arenas: -53.15°, Long: -70.91°	T11	T12	T13	T14	T17	T18

Source: Created by the author with data from INE

Table 3.3: Types of dwellings that make up the sample

Código	Descripción	Superficie (m^2)
T1: VAL1A	Vivienda albañilería de ladrillo un piso aislada	67
T2: VAL1P	Vivienda albañilería de ladrillo un piso pareada	67
T3: VAL2A	Vivienda albañilería de ladrillo dos pisos aislada	75
T4: VAL2P	Vivienda albañilería de ladrillo dos pisos pareada	75
T5: VH1A	Vivienda hormigón un piso aislada	66
T6: VH2A	Vivienda hormigón dos pisos aislada	66
T7: VDHYL	Vivienda departamento hormigón y albañilería de ladrillo	46
T8: VBC1A	Vivienda bloque de cemento un piso aislada	50
T9: VBC2A	Vivienda bloque de cemento dos pisos aislada	75
T10: VBC2P	Vivienda bloque de cemento dos pisos pareada	75
T11: VM1A	Vivienda de madera 1 piso aislada	50
T12: VM1P	Vivienda de madera 1 piso pareada	50
T13: VM2A	Vivienda de madera dos pisos aislada	80
T14: VM2P	Vivienda de madera dos pisos pareada	80
T15: VPS1A	Vivienda panel SIP un piso aislada	66
T16: VFC1A	Vivienda ferrocemento un piso aislada	66
T17: VFC2A	Vivienda ferrocemento dos pisos aislada	75
T18: VFC2P	Vivienda ferrocemento dos pisos pareada	75
T19: VALM2A	Vivienda albañilería de ladrillo, segundo piso en estructura liviana de madera aislada	75
T20: VALM2P	Vivienda albañilería de ladrillo, segundo piso en estructura liviana de madera pareada	75

Source: Created by the author with data from INE

3.1.1.2. Housing models

Paying attention to building types and their average sizes, 20 real residential architecture projects are selected that serve as models or patterns for the purposes of energy assessment. The sources of information include architectural projects provided by construction and real estate companies that collect data on the current, most distinctive architectural characteristics and technologies for housing construction that the market offers in the different regions of Chile. These projects are used to establish a baseline of energy demand and quality for housing construction in 2011.

Projects are repeated in some provinces, with changes only in thermal protection. For example: a concrete apartment, the same model is present throughout the country with very small morphological and size differences, except in thermal protection.

In Figure 3.1 details of the architecture of the housing model identified as T1 VA1LA are presented. These correspond to a detached, one-floor, masonry building with 63 m² of constructed surface area. Appendix 2 presents the architecture of some of the most representative models.

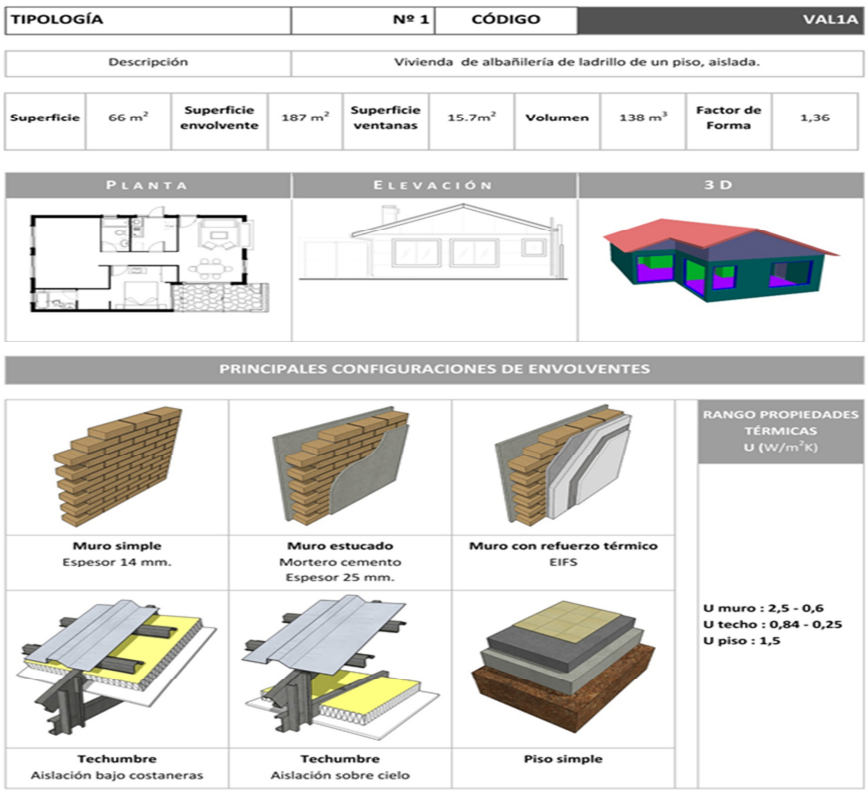


Figure 3.1. Architecture and details of the T1 VAL1A model
Source: Created by the author

3.1.1.3. Thermal insulation of the housing models

The usual practice in Chile is to use only the obligatory standards for thermal insulation. This is the case in all areas except the south central zones, where wood and other systems are normally used for construction, which by nature far surpass the minimum statutory standards. Generally, this includes wood

construction or panels that incorporate expanded or injected insulating material.

For the purposes of the study, the thermal insulation of housing models in the different zones of the country is established by taking into account the following criteria:

- The enveloping thermal insulation that is achieved naturally when this insulation exceeds the zone's regulatory limit.
- The statutory thermal insulation when the natural thermal protection is less than that regulated. In these cases, reinforcements are incorporated.

The minimum statutory levels of thermal insulation are given in Table 3.5 for the different thermal zones into which the national territory is subdivided. These levels often tend to use masonry construction and conventional concrete, which are in the majority from thermal zone 4 to 7. Consequently, diverse thermal reinforcements are used including EIFS or similar systems.

Table 3.4: Thermal insulation of elements of the envelope of dwellings. Valores límites por zona térmica según la reglamentación térmica de Chile.

Zona térmica	Localidad representativa	U – techo (W/m^2 K)	U – muros (W/m^2 K)	U - pisos ventilados (W/m^2 K)
1	Arica	0,84	4,0	3,60
2	Valparaíso	0,60	3,0	0,87
3	Santiago	0,47	1,9	0,70
4	Concepción	0,38	1,7	0,60
5	Osorno	0,33	1,6	0,50
6	Castro	0,28	1,1	0,39
7	Pto. William	0,25	0,6	0,32

Source: MINVU

3.1.1.4. Airtightness of the housing models

For the purposes of the study, the airtightness of the housing models in the different zones of the country are determined using the following criteria:

Properties of the airtightness of housing models are assumed to be the same as those determined in the baseline study of air leakages in Chile for the different building types. These properties are established as a result of an extensive field study conducted between 2012 and 2013, which measured a statistically representative sample consisting of 191 residential units of different types. This research was undertaken in the context of the Fondef project D10 I1025, whose director is the author of this thesis (Bobadilla, 2014). These values are reported in Table 3.5.

Table 3.5: Baseline of air leakage in residential construction in Chile by predominant materiality in walls.

Materialidad	Valor Línea Base n50 (1/h)	Mínimo Valor Muestra n50 (1/h)	Máximo Valor Muestra n50 (1/h)	Valores esperados con un 95% de confianza	
				Máx. n50 (1/h)	Mín. n50 (1/h)
Hormigón	9,0	2,6	28,6	7,8	11,2
Ladrillo	11,8	4,3	19,6	10,9	13,4
Ladr. /Estructura Liviana	15,0	2,3	49,2	11,7	13,8
Madera	24,6	4,5	49,8	18,6	30,6
Otras Combinaciones	10,2	3,3	15,7	7,9	12,6
Hermeticidad media construcción habitacional: 12,9 1/h a 50 Pa con valores esperados entre 11,1 y 14,7 1/h con un 95% de confianza					

Source: Fondef D10 I1025

3.1.1.5. Normalized or standardized infiltration coefficients

The normalized or standardized infiltration coefficient links the property of airtightness, which is typical of the envelope of each type of building, with the variables of local climate. It is used to measure the energy burden from air leakage through energy simulation programs.

For the purposes of the study, standardized infiltration indicators are established, according to the following criteria:

- Standardized infiltration indicators in the construction, obtained through the LBL model developed at the Lawrence Berkeley Laboratories (Sherman & restraint, 1986). These coefficients are characteristic of a building type and the zone or locality where it is found.

- Standardized infiltration indicators by province depending on the building type present in each province and the constructed area. This coefficient provides a measure of the standardized infiltration of provincial housing stock as a reflection of the standardized infiltrations in the different building types present in the province and their relative share in the composition of the housing stock.

To determine these air permeability coefficients, characteristics of the construction and the external environment in which it is located, the LBL model developed at the Lawrence Berkeley Laboratories was used, in the manner explained in the ASHRAE Fundamental of 2009. There is a basic and another more advanced version of the model that differ in the character and type of information they require. For the purposes of this work, the basic model was used because it directly links the measurement data and it uses general information about building types. The advanced model requires more detailed definitions of the dwelling and it was only used to collate the obtained responses with some of the dwellings.

The method is suitable for analysis of housing located in the same zone, where the air is well mixed. The flow from infiltration through the envelope is calculated statically by superposition of the wind contributions and stack effect. The model considers airtightness properties typical of the building,

specifically the effective area for air leaks to 4 Pa, obtained through pressurization tests, with meteorological and physical variables of the place and typical characteristics of the design of the buildings.

3.1.1.5.1. Model for calculation of basic LBL infiltration.

With the model, air flow rates from infiltration and characteristic infiltrations can be obtained. These are calculated as follows:

$$Q = \frac{A_L}{1000} X \sqrt{Cw \cdot \Delta t + C_w \cdot U^2}$$

$$Ic = Q/V$$

Where:

Q: Rate of air flow, m^3 / s
A_L: Effective leakage area, cm^2
Cs: Stack coefficient, $(L / s)^2 / (cm^4 K)$
Δt: Difference of average temperature for interval of calculation time, K
C_w: Wind coefficient, $(L/s)^2 / [cm\ 4\ (m / s)^2]$
U: Average wind speed for interval of calculation time, m / s
Ic: Standardized or characteristic air leakage, 1/h
V: Interior volume enclosed by the building envelope, m^3

The characteristic coefficients Cs are presented in Table 3.6 for dwellings of up to three floors. The value of the wind coefficient Cw depends on the kind of exposure of the residence and the altitude at which it is located. The types of exposure are presented in Table 3.7 and the wind pressure coefficient Cw by kind of exposure and altitude is presented in Table 3.8. Temperature and average wind speed data were taken from the standard NCh 1079 Of.2008 and from the climate archives generated in the project when this information was not available in the regulation. The interior volume corresponds to each housing reference model.

The effective leakage areas AL (cm²) are presented in Table 3.9. These indicators are collected from the baseline study of the housing stock. They correspond to average values by building typology, which are deducted directly from the ELA indicator (cm² /m²) that the pressurization test (Blower Door) determines to 4 Pa.

Table 3.6: Stack coefficients from the LBL model

	Altura en pisos		
	uno	dos	tres
Coeficiente Stack	0.000 145	0.000 290	0.000 435

Source: ASHRAE Fundamental 2008

Table 3.7: Classes of local protection

Descripción de clases de obstrucciones	
1	No hay obstrucciones o apantallamientos locales.
2	Protección típica para una vivienda aislada rural.
3	Protección típica causada por edificaciones en la acera frente a la vivienda en estudio.
4	Protección típica para edificaciones urbanas en sitios grandes, donde los obstáculos están ubicados a una distancia mayor a la altura del edificio en estudio.
5	Protección típica causada por edificios u otras construcciones ubicadas a una distancia menor a la altura del edificio en estudio. Por ejemplo, viviendas al mismo lado de la calzada, árboles, arbustos, etc.

Source: ASHRAE Fundamental 2008

Table 3.8: Wind coefficients Cw from the LBL model

Clase	Altura en pisos		
	uno	dos	tres
1	0.000319	0.000420	0.000494
2	0.000246	0.000325	0.000382
3	0.000174	0.000231	0.000271
4	0.000104	0.000137	0.000161
5	0.000032	0.000042	0.000049

Source: ASHRAE Fundamental 2008.

Table 3.9: Average ELA values for different construction typologies

Tipo de construcción básica	ELA (cm^2/m2 envolvente)
Hormigón	2,9
Ladrillo	3,9
Ladrillo-Madera-Ladrillo-Metalcom	3,6
Madera	6,7
Metalcom	3,3
Other combinations	1,4
Panel EPS Armado Estucable	1,1
Panel Ferrocemento	3,7
Promedio general	3,7

Source: Fondef D10 I1025

3.1.1.5.2. Improved LBL infiltration calculation model.

This model, developed by Walker and Wilson (Walker and Wilson, 1998), uses the parameters of power law to separately calculate the flows due to wind pressure and the chimney or Stack effect. This calls for a more detailed description of the building, but uses the same superposition equation and coefficients as the basic infiltration model to determine the flow rate of air leakage.

The prediction accuracy of the improved model can be very good, typically ± 10%, when the coefficients are well known for the building in question (Palmiter and Bond 1994; Sherman and Modera 1986, Walker and Wilson 1998). Models of a single zone are sensitive to the entry values; hence, the quality of the prediction, as in any numerical tool, is in direct relation also, with the quality of the information that is used.

The model makes it possible to obtain the rates of air flows from infiltrations and characteristic infiltrations, separated by chimney and wind effect, and calculated as follows:

$$Q = \sqrt{Q_s^2 + Q_w^2}$$

Where:

Q: Air flow rate, (m^3 /s)
Q_s: Flow from chimney effect, (m^3 /s)
Q_w: Flow from wind effect, (m^3 /s)

Flow from chimney effect:

$$Q_s = cC_s \cdot \Delta t^n$$

Where:

c: Flow coefficient $m^3/(s/P_a^n)$
C_s: Chimeny coefficient, $(P_a/K)^n$

Flow from wind effect:

$$Q_w = cC_w \cdot (sU)^{2n}$$

Where:

C: Flow coefficient, (m^3 (/s/Pa^n)
C_s: Stack coefficient, (Pa/K)
C_w: Wind coefficient, (Pa s^2 /m^2)
s: Protection Factor
U: U weather (m/s)

The wind coefficients (C_W) and stack (C_S) in this equation are defined in Table 3.10; the flow coefficient *c* and the pressure exponent *n* are obtained from measurements carried out through pressurization tests. Wind speeds are multiplied by the corrector G, according to Table 3.11.

Table 3.10: Multiplier of wind speed G

	Altura vivienda (en pisos)		
	uno	dos	tres
Multiplier of wind speed G	0,48	0,59	0,67

Source: ASHRAE Fundamental 2008

Table 3.11: Stack and wind coefficients for improved LBL infiltration calculation model

	Un piso		Dos pisos		Tres pisos	
Chimenea	**Sin**	**Con**	**Sin**	**Con**	**Sin**	**Con**
C_s:	0,054	0,069	0,078	0,089	0,098	0,107
C_w para losa de hormigón	0,156	0,142	0,170	0,156	0,170	0,167
C_w para piso ventilado	0,128	0,128	0,142	0,142	0,151	0,154

Source: ASHRAE Fundamental 2008

The LBL model thus determined, makes it possible to establish standardized or characteristic infiltration coefficients In (1/h) by dwelling model and locality. It should be noted that this coefficient is assumed as 1(1/h) in the official tools for calculating energy demands in Chile. This definition supposes that all the buildings in Chile have the same level of airtightness and all the constructions in the same place have the same energy load from air leakage. The same value is often used by default in energy studies of a similar nature, in the absence of reliable information.

Differentiation in the consideration of air leakages, due to both climate as well as building system, for the study of energy demand in this work, is an innovation in the management of these areas in Chile: for the first time, the typical properties of airtightness in housing stock in Chile are being considered. This new approach gives a more accurate estimation of the energy quality of the housing stock and its baseline. It also improves differentiation between the quality of different building systems.

3.1.1.6. Meteorological databases

To determine the energy demand of the building stock, it was necessary to create new meteorological databases to cover the 54 provinces of Chile and to make improvements to the existing databases. The new databases include time information on weather variables in the 54 provincial capitals of Chile.

They are obtained through a process of adaptation and validation of the databases that the Meteonorm software generates (Meteonorm, 2012).

Data was corrected and adapted using the adjustment method used at the University of Southampton (Hampton J., 2013), which was originally used to correct the effects of global warming on the weather databases. With this methodology, the time response of the Meteonorm databases is modified so as to coincide with the official monthly information that NCh1079 (INN 2008) and other specific local sources provide (Gonzalez A. and others 2013).

The database validation process involved contrasting the responses the databases provide on two levels: On a first level, with quantitative information that different sources give for some cities and not necessarily for building design purposes, such as Rioseco and Tesser's interactive cartography of the climates of Chile from the Institute of Geography at Pontificia Universidad Católica of Chile (2013); Sarmiento's solar radiation tables by the Laboratory of Solar Energy and Evaluation at Universidad Técnica Federico Santa María (2008); Fontannaz's (2001) Weather Statistics; the National Institute of Statistics, Environment, Annual Report 2009 and NCh 1079. On a second level of validation, databases are contrasted based on qualitative information from Köppen's climate classification. Degrees of coincidence between the thermal thresholds of the classification and types of weather for each locality are verified. Finally, a level of precision is achieved that is adequate for the purposes of this study.

Figure 3.2 shows the customized responses of the new database with respect to those obtained directly by using Meteonorm's climate generation program and the corrected database for the specific case of the city of Calama.

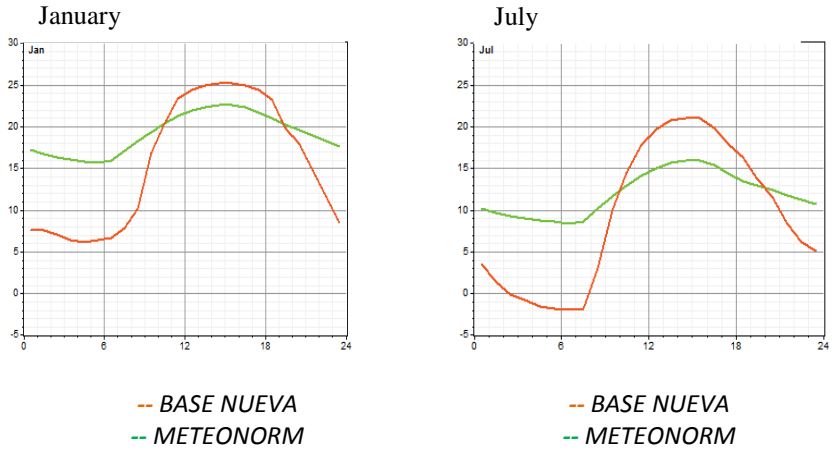


Figure 3.2: oscillation of average monthly temperature in the city of Calama in the months of January and July. Base response with and without correction. Source: Created by the author.

This preparatory work, which was not originally envisaged, was necessary due to the lack of meteorological data schedules in some cities and the errors produced by the climate generation programs in various localities. The NCh1079 standard provides meteorological information with a return period of 30 years, which is understood to be official regarding the weather in Chile. However, the data is reduced to average monthly values that are not appropriate for the purposes of carrying out energy simulations. Other sources such as the National Oceanic and Atmospheric Administration (NOAA) (http://www.noaa.gov/) and the International Weather for Energy Calculations IWEC (http://apps1.eere.energy.gov/) from the United States Agency for Energy Efficiency, also both examined for the purposes of this study, either do not cover all the locations of interest or do not give all the information required.

The official tools used in Chile's energy certification program, the CCLT_CL and CEV_V1.0 Program, use the weather databases of only seven major cities for the calculation of energy demand. These are understood to

be representative of each of the seven Chilean thermal zones (Fissore and Colonelli, 2008). Many energy and environmental studies of buildings tend to do the same; in the absence of weather databases with time data, they assume information for nearby cities, in this way often incurring serious assessment errors. From the ocean to the mountains, at a relatively minor geographical distance, less than 200 km, localities can be found between 0 and 3,000 meters above sea level, with substantive differences in climate. The same occurs from the north to south of the country, over more than 4,000 km. The thermal zoning and the weather databases commonly used, as highlighted in chapter 2, do not adequately reflect the behavior of climate variables important for the hygrothermal design of buildings, such as thermal oscillation, humidity, and wind speeds.

3.1.1.7. Simulation Tools

The energy assessments were carried out using the commercial program TAS version 9.2.1.4, the universally accepted tool for this application. This program uses a multi-zone thermal model to simulate the energy and environmental behavior of a building in a dynamic state. It also enables the differentiation of thermal loads due to air leakage, which is particularly appropriate for the study.

TAS (Thermal Analysis Software) is a dynamic modeling simulation tool, which was originally designed at Cranfield University and has been sold since 1984. It complies with the calculation methodology required in England and is typically used to simulate the thermal behavior of both new and existing buildings. The software is mainly used by engineers, architects and academics. It is an application that is also used for the development of Energy Efficiency Certificates (NEP levels 3, 4, and 5). It complies with the 2010 L2 norm (including that of 2006 and the methodologies of 2010). TAS

is particularly useful for studies of overheating, and heating and cooling operation. It is also every appropriate for evaluation studies of environmental performance, analysis of natural ventilation, prediction of energy consumption and analysis of design strategies. It consists of several validations including ASHRAE 140-1 (2004), ASHRAE 140-1 (20 07), EN ISO 13791 and CIBSE TM33.

3.1.1.8. Simulation parameters and conditions

In Table 3.12, the principal assumptions and parameters used in the simulation process are summarized. The program and occupation loads, the ranges of comfort and the periods of service of conditioning systems are the assumptions and parameters used by the thermal behavior certification program for buildings in Chile CCTE V2.0 (Ministry of Housing and Urban Development, 2002). They are duly agreed upon in Chile for purposes of this nature. Architecture and thermal parameters of the models that serve as reference are explained in Appendix 2.

Table 3.12: assumptions of occupation, range of comfort and periods of demand

CARGAS INTERNAS	
Carga sensible	Lunes a Viernes : 30,16 kWh/m^2 día Sábado a Domingo : 51,6 kWh/m^2 día
Carga latente	Lunes a Viernes: 19,04 kWh/m^2 día Sábado a Domingo : 32,64 kWh/m^2 día
Iluminación	Lunes a Domingo : 39,6 kWh/m^2 día
Equipos	Lunes a Domingo: 39,6 kWh/m^2 día
Rango de Confort	
Todo el año	20-25 °C
Temporadas de calefacción y enfriamiento	
Temporada calefacción	Todos los meses con más de 50 grados día
Temporada enfriamiento	Todos los meses con más de 50 grados día

Source: MINVU

3.1.2. Standardized infiltrations

Table 3.13 shows the characteristic standardized infiltration coefficients by building typology in the cities of Antofagasta, Santiago, Concepción and Punta Arenas. In addition, the same table indicates the weighted characteristic standardized infiltration coefficient in the province. This indicator takes into account the participation, by built surface area, of the different types of building present in the housing stock registered in 2011 in each province.

Table 3.14 shows the standardized infiltrations, weighted in the manner explained above, in the 54 provinces of Chile. Appendix 3 presents in detail the characteristic infiltrations by building type in the different provinces. These infiltration coefficients link local climate variables with the airtightness properties typical of the buildings.

In 14 of the 54 provinces, the standardized infiltration coefficients are less than or equal to 1 (1/h), within the range 0.7 -1.0 (1/h). They are associated with inland localities, mainly in the north-central zone of the country, some of them with microclimates compatible with average wind speeds less than 2.5 m/s and several months of the year with calm weather (less than 2.0 m/s). Some localities are also compatible, in some cases, with relatively high average exterior temperatures, which minimize the effects of thermal draft. The higher weighted provincial values are in the range of 1 and 2.9 (1/h) and are associated with coastal localities, mainly in the south-central zone, with average annual speeds above 2.5 m/s and/or average low temperatures. The variations in standardized infiltrations by building typology and province are quite larger and range from 0.4 (1/h) for an isolated, 1 floor building of concrete block in the city of Vallenar (annual average speeds less than 2.0 m/s and an average temperature of 14.9 ºC) and 4.0 (1/h) for an isolated, 1

floor building of wood in Punta Arenas (average annual wind speed of 8.2 m/s and an average temperature of 5.9 °C). Punta Arenas is an extreme case due to the coincidence of rigorous exterior climate conditions (mainly due to the high wind speeds) with construction systems with low airtightness (highly permeable to air), as is the case with the wooden buildings in Chile today. A different situation explains the case of the city of Vallenar.

The highest values in Chile are associated with wood construction and the lowest values with concrete. In the provinces where the impact of infiltration is greater, constructive systems coincide with less air tightness. Mainly localities in the south-central area of the country, where timber and distinct board-type panels are the preferable method of construction, light construction in general, currently present the lowest standards of airtightness in Chile.

These differences in characteristics related to air permeability in the buildings of the housing stock also determine differences in the energy demands associated with infiltrations. This validation explains the moderate and almost non-existent progress achieved in many localities related to the reduction of energy intended for the thermal conditioning of buildings. The high levels of air leakage, quite undervalued in Chile when calculating and predicting energy demand, explain this issue to a great extent.

The impact of improvement measures associated with sealing and airtightness is different depending on the location and the type of building. The relationship between the loads from infiltration and transmission is also different and can be better appreciated now as a result of this study. All of this information enables an improvement in the orientation of the design strategies of new dwellings and the thermal reconditioning of the existing stock.

Table 3.13: Standardized infiltration coefficients In (/h) by typology of buildings present in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas

	Antofagasta		Santiago		Concepción		Punta Arenas	
	In 1/h	factor	In 1/h	factor	In 1/h	factor	In 1/h	factor
T3: VAL2A			0,9	0,1	1,4	0,2		
T6: VH2A	1,1	0,1	0,9	0,04	1,5	0,1		
T7: VDHYL	2	0,9	1,6	0,8	2,6	0,1		
T11: VM1A					2,3	0,1	2,9	0,2
T12:VM1P							4,0	0,1
T13:VM2A					2,7	0,1	3,3	0,1
T14:VM2P							3,3	0,3
17:VFC2A					1,2	0,1	2,1	0,1
T18:VFC2P							1	0,1
T19:VALM2A					1,4	0,4		
Infiltración normalizada Provincial	1,9		1,5		1,7		2,8	

Source: Created by the author

3.1.3. Energy demand in the different provinces of Chile

Table 3.15 presents the energy demands by structural typology present in the cities of Antofagasta, Santiago, Concepción and Punta Arenas. Demands are also listed for heating, cooling, and total energy, considering the load associated with the standardized infiltrations for each type of building in the province. Similarly, the table includes the weighted demand by province, an indicator that considers the participation, by built surface area, of the various building types in the housing stock.

Table 3.15 presents the weighted provincial energy demands by built surface area, of the main types of buildings present in the various provinces. These demands are measured with the corresponding infiltration coefficients 0 (1/h), 1 (1/h) and standardized coefficient In (1/h). Figures 3.3 and 3.4 graphically illustrate the demands in order to better appreciate the dispersions.

From these tables and figure, the map was derived of energy demands by province for the thermal conditioning of housing stock with a 2011 building permit in Chile. At that level, the predominance of heating needs in residential buildings in Chile can be observed. 21 of the 54 provinces only report heating needs; in 31 provinces combined demands of heating and cooling are presented, of which in 18 cooling demands do not exceed 15 kWh/m²year and in 2 do not exceed 28 kWh/m² year and; in 2 only cooling requirements are presented. These are mostly concentrated in northern provinces and some in the center of the country, including Santiago.

Heating requirements are present in virtually the entire national territory, mainly in the Andean and south-central zones of the country. In 45 of the 54 provinces, the demand exceeds 100 kWh/m²year, in 15 provinces it exceeds 200 kWh/m²year and in 4 provinces it exceeds 400 kWh/m²year. All these indicators denote a low level of energy quality in the stock of new buildings in Chile.

The energy load associated with air leakages varies significantly and impacts in different ways depending on the type of energy demand. In the provinces with predominant heating needs (only heating needs, or cooling demand does not exceed 10% of that of heating) infiltrations import demands that are between 23 and 203 kWh/m²year and can represent between 20 and 50% of the total energy demand for thermal conditioning. On the other hand, the standardized infiltrations with respect to the reference level 1(1/h), in localities where these are higher (in 40 of the 54 provinces of Chile), mean higher general energy demands on average per province, 20% and 40% in the most extreme cases of Punta Arenas and Chile Chico.

Table 3.14: Weighted standardized characteristic infiltration by province

Localidad	Infiltración normalizada ponderada (1/h)	Velocidad media anual de viento (m/s)	Temperatura media exterior (°C)
Vallenar	0,7	Calmo	14,9
Illapel	0,7	2,2	14,0
Linares	0,7	3,3	13,2
Puente Alto	0,8	3,6	14,2
Temuco	0,8	Calmo	11,2
Tocopilla	0,9	3,1	18,1
Quillota	0,9	2,5	14,1
Colina	0,9	2,7	14,0
San Bernardo	0,9	3,6	14,1
Melipilla	0,9	2,7	14,1
Rancagua	0,9	3,1	13,5
San Fernando	0,9	3,1	13,9
Chañaral	1,0	5,7	16,9
Hanga Roa	1,0	4,9	20,5
Curicó	1,0	3,1	13,1
Valdivia	1,0	Calmo	11,0
La Unión	1,0	Calmo	11,3
Chaitén	1,0	3,8	10,4
La Ligua	1,1	2,4	14,1
Talagante	1,1	3,6	14,1
Talca	1,1	3,1	14,0
Osorno	1,1	Calmo	10,5
Castro	1,2	2,2	13,4
Angol	1,2	2,4	13,2
Los Ángeles	1,2	2,4	13,2
Porvenir	1,2	2,8	6,2
Iquique	1,2	3,1	18,0

Localidad	Infiltración normalizada ponderada	Velocidad media anual de viento (m/s)	Temperatura media exterior (°C)
Chillán	1,3	3,1	12,7
Arica	1,3	5,1	18,7
Pichilemu	1,3	5,6	14,0
San Felipe	1,3	5,6	14,6
Puerto Montt	1,3	4,6	10,1
Coquimbo	1,4	4,1	13,8
Santiago	1,5	3,6	13,6
Coyhaique	1,5	5,1	8,1
Ovalle	1,5	5,5	14,4
Quileute	1,5	5,6	13,9
Pozo Almonte	1,5	8,5	12,3
Putre	1,5	8,7	12,4
Puerto Aysén	1,6	4,6	9,0
Cauquenes	1,6	7,0	14,2
Puerto Natales	1,7	2,8	6,1
Copiapó	1,7	5,1	15,2
Concepción	1,7	6,7	12,2
Antofagasta	1,9	5,1	16,4
Los Andes	1,9	5,5	14,5
San Antonio	2,1	5,6	13,8
Puerto Williams	2,1	5,7	6,0
Valparaíso	2,2	6,2	14,0
Lebu	2,3	7,0	12,3
Cochrane	2,7	6,6	7,7
Calama	2,8	8,2	5,9
Punta Arenas	2,8	8,2	5,9
Chile Chico	2,9	9,8	9

An analysis at the structural type level by province generates more significant differences, given that the average values hide the marked dispersions observed in those provinces where there are building systems with very different airtightness properties.

The localities that demand more energy are Puerto Williams, Punta Arenas, Puerto Natales, Chile Chico and Pozo Almonte, all of which have weighted provincial energy demands surpassing 325 kWh/m²year. On the other hand, the localities that least demand energy are Arica, Iquique and Tocopilla, with values less than 28 kWh/m² per year, corresponding to only cooling demands. In the provinces where cooling requirements predominate (only cooling is required or heating demand does not exceed 10% of that of cooling), 4 of the 54 provinces of Chile, infiltrations help to reduce energy consumption.

Dwellings located in localities in the Andean zone, which ranges from the north to the south of the country, have demands greater than 200 kWh/m²year. Although high, these demands are expected considering the harsh climate in this area and the typically low levels of thermal protection in the buildings in that territory. From north to south, in inland areas, progressive demands can be observed in general terms, ranging from a bit more than 10 kWh/m²year in Arica and Tocopilla (cooling), up to more than 400 kWh/m²year in Punta Arenas and Puerto Williams (heating), which are explained in the same way. Likewise, clear differences between localities separated by relatively minor geographical distances within the same thermal zones (regulations) and even climatic zones (NCh 1079) can be observed in a transverse direction.). Examples: Curicó (141 kWh/m²year) and Talca (129 kWh/m²year); Rancagua (113 kWh/m²year) and San Fernando (137 kWh/m²year); Angol (110 kWhm²year) Temuco (202 kWh/m² year); etc. The influence of topography, altitude and regional weather conditions, which

create numerous microclimates, seems to explain this situation, which is also noted when observing the standardized infiltrations of buildings in different provinces.

The significance of this situation is not minor and obliges the review not only of thermal insulation standards, but also of the zoning for architectural design purposes in Chile. In concrete terms, it can be observed that the thermal insulation of buildings is not properly adjusted to the climatic variables of each locality. Substantive differences can be perceived in the capacity of homes to limit energy demand, which also indicates differences in suitability for use in different provinces.

It should be remembered that in this case, in the analysis of demand, demand is weighted due to infiltration, considering the characteristics of the building. With this information, a territorial map of different energy demands is generated, which is considered to be much closer to reality. The loads from infiltration, as has been noted, are of very different magnitudes in the 54 provinces of Chile. Primarily wind pressure and to a lesser extent thermal differentials, determine very heterogeneous loads from infiltration throughout the country, which the cited Tables and Figures reflect.

The physical geography of the nation, its particular orography and topography, and the altitude and nature of the terrain generate microclimates and wind patterns that vary from almost permanently calm in some localities to nearly extreme situations in others within the same region. Consequently, what seems to be more appropriate for the purposes of setting requirements, is to define more than just a thermal zone, but the province as a territorial unit. The climatic zoning proposed by NCh 1079 does not completely resolve the problem. Neither does the thermal zoning the regulation establishes. In both, thermal requirements and local climate are

disconnected. The distinctive features of the national weather make it more advisable to define rather than the thermal zone, the province, as a territorial unit in order to set airtightness requirements.

Table 3.15: Energy demand of residential buildings in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas.

Parám.	PROVINCIA - TIPOLOGÍA																	
	Antofag.		Santiago			Concepción							Punta Arenas					
	T6: VH2A	T7: VDHYL	T3: VAL2A	T6: VH2A	T7: VDHYL	T3: VAL2A	T6: VH2A	T7: VDHYL	T11: VM1A	T13:VM2A	T17:VFC2A	T19:VALM2A	T11: VM1A	T13:VM2A	T12:VM1P	T14:VM2P	17:VFC2A	T18:VFC2P
In	1,3	1,0	0,9	0,9	1,6	1,4	1,5	2,6	2,3	2,7	1,7	1,4	2,9	3,3	4,0	3,3	2,1	1,0
Cei	24	22	37	31	63	61	66	112	106	117	75	61	238	258	336	256	169	81
Dec	86	60	97	104	60	114	94	74	125	93	149	175	273	197	248	183	237	226
Der	9	8	11	12	9	-	-	-	-	-	-	-	-	-	-	-	-	-
Dett	120	89	145	147	131	175	160	186	231	210	225	236	511	455	585	439	406	307
Depp	92		134			207							449					

Source: Created by the author

In : Standardized infiltration coefficient (1/h)
Cei : Energy load from infiltration (kWh/m^2 year)
Der : Energy demand for cooling (kWh/m^2 year)
Dec : Energy demand for heating (kWh/m^2 year)
Dett : Total energy demand by building type (kWh/m^2 year)
Detp : Total weighted provincial energy demand (kWh/m^2 year)

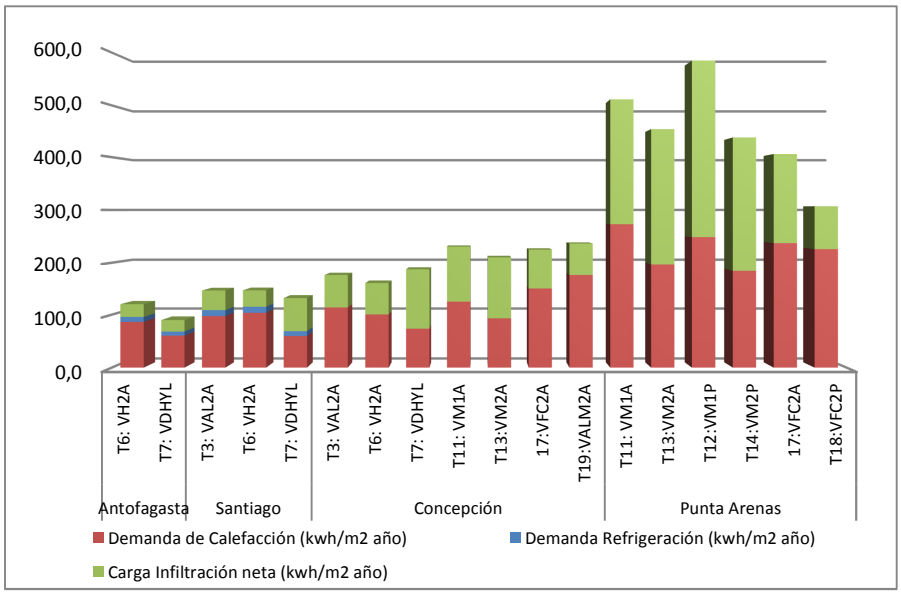


Figure 3.3: Energy demand of residential constructions in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas. Source: Created by the author.

Table 3.16: Weighted energy demands by provincial capital. Demands with different energy load due to air leakages.

Localidad		Arka	Putre	Iquique	Pozo Almonte	Tocopilla	Calama	Antofagasta	Chañaral	Copiapó	Vallenar	Coquimbo	Ovalle	Illapel	La Ligua	Los Andes	San Felipe	Quillota	Valparaíso	San Antonio	Hanga Roa	Quilpué	Colina	Santiago	Puente Alto	San Bernardo	Melipilla	Talagante
Det_o	(kWh/m² año)	19	135	21	297	12	137	70	54	75	74	91	79	127	90	74	109	113	53	73	34	51	106	77	103	98	109	114
In	(1/h)	1,3	1,5	1,2	1,5	0,9	2,8	1	1	1,7	0,7	1,4	1,5	0,7	1,1	1,9	1,3	0,9	2,2	2,1	1	1,5	0,9	1,5	0,8	0,9	0,9	1,1
Detp	(kWh/m² año)	21	209	28	378	11	269	93	60	104	92	133	113	168	124	138	152	151	111	119	35	110	140	133	134	148	130	160
Decp	(kWh/m² año)	0	209	20	367	0	259	79	49	76	81	122	93	143	100	116	119	133	111	119	1	110	124	119	117	134	109	149
Derp	(kWh/m² año)	21	0	9	10	11	9	14	11	28	11	11	20	26	23	22	33	18	0	0	33	0	16	14	17	14	21	10
Det_1	(kWh/m² año)	16	185	27	349	11	186	93	60	94	99	121	103	180	121	110	143	154	81	96	35	97	143	115	144	152	133	155
Dec_1	(kWh/m² año)	0	185	18	340	0	177	79	48	62	89	111	82	154	98	89	111	136	81	96	1	97	127	101	126	138	112	145
Der_1	(kWh/m² año)	16	0	9	9	11	9	14	11	32	11	10	21	26	23	20	31	18	0	0	33	0	16	14	18	14	21	10
Detp- Det_1	(kWh/m² año)	0	24	1	29	0	83	0	0	10	-7	12	10	-12	3	28	9	-3	30	23	0	13	-3	18	-10	-4	-3	5
Detp- Det_o	(kWh/m² año)	-3	74	7	81	-1	132	23	6	29	18	42	34	41	34	64	43	38	58	46	1	59	34	56	31	50	21	46

Localidad		Rancagua	San Fernando	Pichilemu	Curicó	Talca	Linares	Cauquenes	Chillán	Los Ángeles	Concepción	Lebu	Angol	Temuco	Valdivia	La Unión	Osorno	Puerto Montt	Castro	Chaitén	Coyhaique	Puerto Aysén	Chile Chico	Cochrane	Puerto Natales	Punta Arenas	Porvenir	Puerto Williams
Det_o	(kWh/m² año)	92	109	78	106	87	111	99	89	91	73	79	75	155	117	108	137	137	145	155	181	161	187	117	221	213	199	281
In	(1/h)	0,9	0,9	1,0	1,0	1,1	0,7	1,6	1,3	1,2	1,7	2,3	1,2	0,8	1	1	1,1	1,3	1,2	1	1,5	1,6	2,9	2,7	1,7	2,8	1,2	2,1
Detp	(kWh/m² año)	113	137	96	141	129	133	159	142	150	180	197	110	202	171	154	195	192	207	201	264	260	364	227	325	446	277	484
Decp	(kWh/m² año)	103	126	96	132	112	123	143	133	136	180	197	104	202	170	154	195	192	199	201	264	260	364	227	325	446	277	484
Derp	(kWh/m² año)	10	11	0	9	17	9	16	9	14	0	0	6	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
Det_1	(kWh/m² año)	126	153	96	141	144	143	139	131	142	148	144	104	215	169	156	191	177	198	201	234	226	248	158	280	301	263	379
Dec_1	(kWh/m² año)	117	143	96	132	128	134	124	122	128	148	144	98	215	169	156	191	177	190	201	234	226	248	158	280	301	263	379
Der_1	(kWh/m² año)	10	11	0	9	16	10	15	9	14	0	0	6	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
Detp- Det_1	(kWh/m² año)	46	50	5	-2	74	-10	20	11	8	32	53	6	-13	2	-2	4	15	9	0	30	34	116	69	45	145	14	105
Detp- Det_o	(kWh/m² año)	80	94	23	33	131	22	60	53	59	107	118	35	47	54	46	58	55	62	46	83	99	177	110	104	233	78	203

Source: Created by the author

Det_o Total provincial energy demand without infiltration

In Characteristic standardized infiltration coefficient

Detp Total energy demand with standardized provincial infiltration

Decp Provincial energy demand for heating

Derp Provincial energy demand for cooling

Det1 Total provincial energy demand with infiltration levels 1 (1/h)

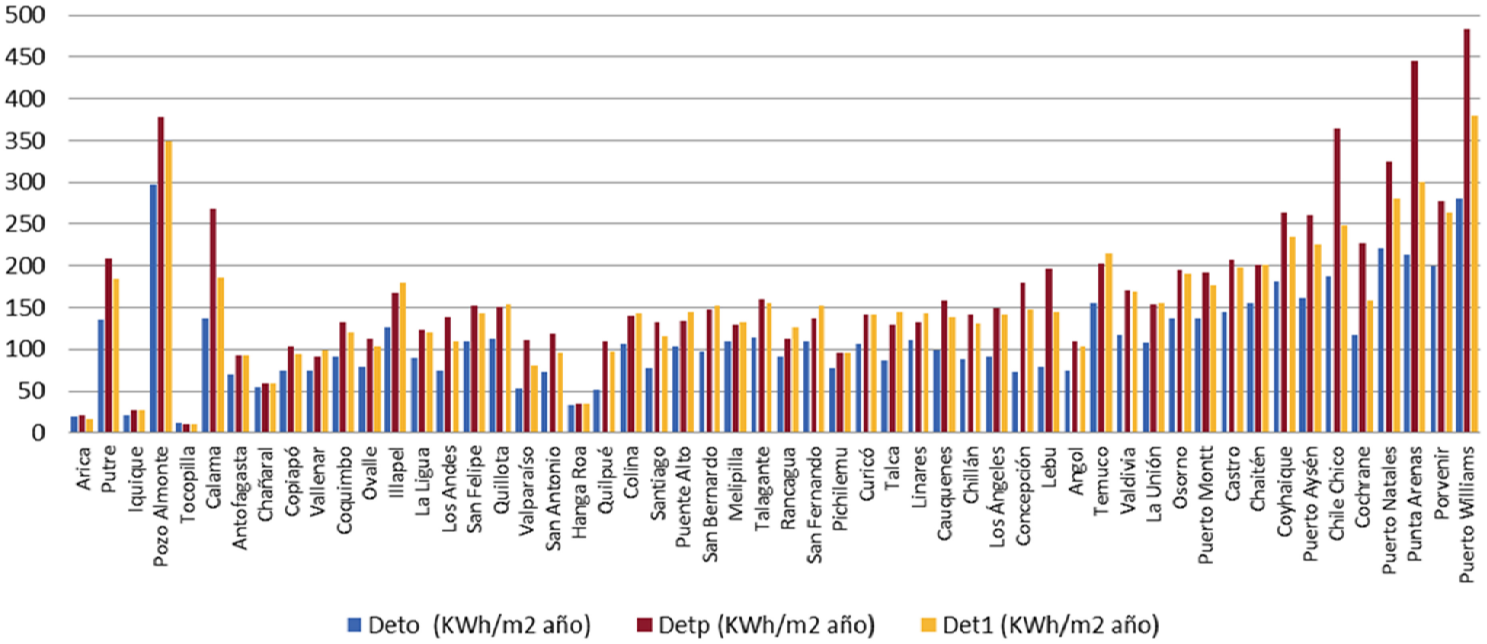


Figure 3.4: Weighted provincial energy demands of residential building authorized in 2011 in the different provinces of Chile. Demands with standardized infiltration, infiltration 1 (1/h) and without air infiltration. Source: Created by the author

3.2. Energy demand references

3.2.1. Methodological aspects

Optimal levels of energy demand are defined and established for the housing stock registered in 2011 in the different provinces of Chile, by province, thermal zone and national total. These levels defined as optimal, serve as references to establish gaps in quality. To set these levels, information and results are collected from research projects contracted by the Ministry of Housing and Urban Planning and the Ministry of Public Works, and carried out under the direction of this author in the last three years.

Three research projects in particular are the main references for this part of the investigation. The first, carried out through the INNOVA CHILE No. 09 CN14-570 project, aimed to comparatively evaluate passive and active design strategies in public buildings through simulation and monitoring techniques[5]. The second, carried out through the FONDEF D09I1162 project, led to the development of methods to evaluate the energy and environmental performance of residential buildings, both in design and the actual building[6]. The third, carried out through the FONDEF D10 I 1025

[5] INNOVA CHILE Project N. 09 CN14-5707: "Evaluation of Structural Design Strategies and Environmental Quality Standards and Efficient Use of Energy in Public Buildings, through Monitoring of Constructed Buildings. This research project was coordinated by the Institute of Building and implemented by a consortium led by CITEC UBB, in which DECON UC, IDIEM and DICTUC also participated. Its objective was to experimentally assess the energy performance and indoor climate of buildings in order to contrast the hypotheses of projected performance, develop optimization strategies and obtain parameters for the certification of the energy efficiency and environmental quality of public buildings in Chile.

[6] FONDEF Project D09I1162 "Design and implementation of a quality assurance system for residential construction projects in Chile based on criteria and performance standards". This project was carried out by CITEC UBB and DECON UC between 2010 and 2013, with the objective of developing a system of quality assurance and certification for housing, based on the control of its performance or

project, led to the establishment of acceptable airtightness standards for residential and service building in Chile[7].

The class of tightness in a locality defines the permissible energy load or loss due to air leakage, which is economically and environmentally justifiable. These classes were defined through the FONDEF D10 I 1025 project recently at the end of 2013. Their definition finally permitted the closure of the equation necessary to determine the optimized energy quality reference levels in Chile, which are presented in this thesis.

Below, the main elements are explained of the methodology used to establish the optimized quality references, that is, the energy quality that housing stock should have if it incorporated criteria for energy efficiency.

3.2.1.1. Pyramidal model of hierarchies

To create judgments on energy quality in residential buildings in the 54 provincial capitals of Chile, their energy demands are compared with reference demands. These demands, by definition in this thesis, set the optimal minimum level of energy for thermal conditioning in each province of Chile and are understood to be optimized energy levels.

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objectives in safety, habitability, durability and environmental sustainability. This system was designed to promote innovation and competitiveness in the construction market and, as a result, the quality and sustainability of dwellings built in Chile.

[7] FONDEF project D10 I 1025: Establishment of acceptable classes of infiltration for buildings in Chile. The main objective of the project is to establish airtightness standards and acceptable classes of infiltration in buildings by territorial area in Chile, with the aim of reducing to acceptable limits the impact of air infiltration on energy demand and consumption in the building sector. In addition, it aims to develop knowledge and technological solutions to support design, implementation and quality control, so as to obtain buildings with airtightness levels adjusted to optimum energy use needs throughout the national territory.

To establish these levels and the techniques and measurement procedures, the method proposed by this author (Bobadilla and others 2012) is used. It was originally developed by commission of the Ministry of Public Works through the Project INNOVA CHILE No. 09 CN14-5707, to evaluate passive design strategies for tertiary buildings in Chile, and later adapted for use in the measurement of performance of residential buildings, in the form used in this thesis, through the Fondef project D 09 I 1962.

The method uses the pyramidal model of hierarchies NKB, developed by the Nordic Committee on Building Regulations (NKB, 1976). This model has served as a base worldwide for the development of instruments and systems of regulatory control in the building sector. The model consists of five hierarchical levels that are summarized in Figure 3.5.

The objectives, found in the highest hierarchy, correspond to the expression of the essential user interests in terms of the dwelling and its parts, which adjust it to the intended use. In the second level are the requirements the materials and elements should meet so as to achieve the foreseen objectives. In the level below this can be found the requirements, which correspond to the specific conditions that make the dwelling design, its building systems and the elements that form it, appropriate for use under specific circumstances. These requirements are expressed through customizable, practical measurement indicators or, conditions or design elements and/or the possible verification processes. In the fourth level are located the verification methods and tools to check and demonstrate that a solution meets the requirements in both design and workmanship. Finally, in the bottom level are the accepted solutions, that is to say, different alternatives that certifiably meet recognized quality levels.



Figure 3.5: NKB pyramidal model of hierarchies
Source: Fondef D09 I 1962

The NKB model is attractive since it puts the focus on social goals (at the policy level) and it permits a variety of forms of the regulatory norms to demonstrate compliance with the requirements. The methods or systems of control are based on the previous precise definition of said performance or risk requirements, and of the performance or risk criteria. This is the value of the requirement or risk that is accepted and whose compliance should in the end verify the systems of quality control.

To rate the energy efficiency of dwellings, a "benchmarking" method is used, as defined by Mandallena, (Mandallena, 2006). It was developed in the context of the FONDEF D09I1162 project, which compares measured performance with references of good, acceptable and bad performance. Such values are observed for the same context of weather, technology, economic opportunities and social expectations. The rating method consists of the following items:

- Performance requirements
- Indicators or means by which performance can be measured
- Performance classes

- Performance criteria expressed in the form of limits or acceptable values
- Techniques and protocols for performance measurement

The method includes seven classes or levels of performance, ranging from level A (very good) to G (very poor), similar to the labeling system for rating the energy efficiency of electrical appliances. The domain defined by the A to G references is determined for each performance, based on the review of the latest local developments and analysis of technical and economic feasibility.

On this scale, the intermediate E level represents the class that is understood to be acceptable or the optimized level. This level is usually defined on the basis of limit values set by: ordinances and national standards when these exist, comparable foreign ordinances with local research and studies, or by previously established agreement and according to existing expectations. The level of optimized demand E, taken as reference in this thesis, is established on the basis of information collected from foreign and national standards and the results of the research projects described above.

Figure 3.6 shows the model of the construction of the method. The main constituent elements for the objectives of rating energy quality are explained below.

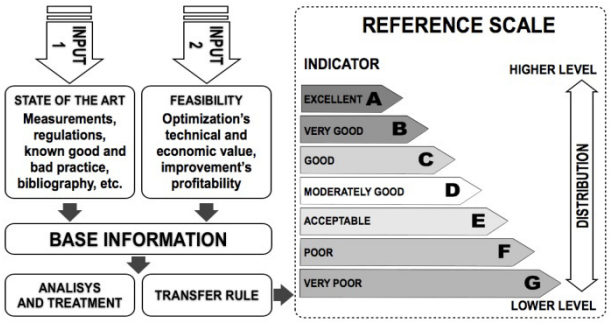


Figure 3.6: Model of the performance rating method. **Source:** Fondef D09 I 1962

3.2.1.2. Requirements and indicators of energy quality

The requirements are defined according to the interests of users and of society. These requirements account for the specific conditions that the design of the building and the elements of which it is made must verify to achieve a certain performance or a previously defined objective. Meanwhile, the indicators are the means or concepts used to measure and verify performance by comparison with the quality references that the rating system defines. In this way, the objective is achieved.

The requirement of energy quality, the way in which it is defined, its indicators and considered metrics are the following: Energy quality, for these effects a synonym of energy efficiency, can be seen through the ability that the building design shows to adequately limit the necessary energy demand to achieve thermal wellbeing depending on the climate of the area, the use of the building, and the summer and winter schedules. This ability is mainly determined by the level of its insulation characteristics, thermal inertia and thermal compactness, permeability to air, exposure to solar radiation and, the risks of condensation occurrence. In summary, an ability is determined by the building's hygrothermal design and is feasibly characterized or represented through a series of thermal parameters that serve as indicators.

The indicators or parameters considered to measure this ability are:

a) Thermal transmittance (W/m²K)
   - Thermal transmittance of facade walls, **Um**
   - Thermal transmittance of walls in contact with the ground, **Ut**
   - Thermal transmittance of roofs, **Uc**
   - Transmittance limit of floors in contact with the ground, **Upt**
   - Transmittance limit of ventilated floors, **Upv**
   - Thermal transmittance of openings, **Uv**

- Thermal transmittance of bridges, **Up**
- Weighted thermal transmittance of vertical envelope, **Upev**

b) Modified solar factor (s/d)
   - Modified solar factor of openings, **Fv**
   - Modified solar factor of skylights, **Fl**

c) Air permeability of facade (1/h)
   - Air Leakage through the envelope to 50 Pa, **Fi**

d) Air permeability of windows (m³/h)
   - Air permeability of windows to 100 Pa, **Pv**

e) Energy demand for (kWh/m²year)
   - Energy demand for heating, **Dec**
   - Energy demand for cooling, **Der**

The last and principal indicator is the energy demand (kWh/m²year), defined as the amount of energy required to compensate for different thermal loads when the building is in use. It is a direct indicator of the ability of the building's passive design to limit the use of energy.

3.2.1.3. Thermal parameter limit values.

The method defines and differentiates three types of parameters: the parameters associated with the transmission of heat, those associated with solar protection and air permeability of the envelope.

The limit values for the transmission of heat through the opaque and transparent envelope for the 9 climatic zones in which the national territory is divided, are collected from the regulation NCh1079.Of 2008 (INN, 2008).

This norm, made official in 2008, uses as a basic criterion the achievement of comfort in buildings through energy efficiency. It recommends transmittance standards consistent with this criterion, higher than those in the thermal regulation of buildings and more appropriate, as recognized in Chile today.

The limit values for the modified solar factor of openings by percentage of openings in each climatic zone are obtained from the European Technical Codes and by assimilation of climatic severity (CTE, 2007).

The limit values for the air permeability of the envelope are those proposed by the Fondef project D10 I 1025. These values correspond to the airtightness requirements for each of the 54 provinces of Chile (Bobadilla A. and others, 2014). The limits are set at the level of airtightness that presently 10% of the housing stock of new buildings in each province meet and/or, at which the associated energy load does not exceed 40 kWh/m²year.

Appendix 4, sections 4.1 and 4.2, presents the limit values for the thermal parameters of envelopes in different climatic zones and provinces of Chile.

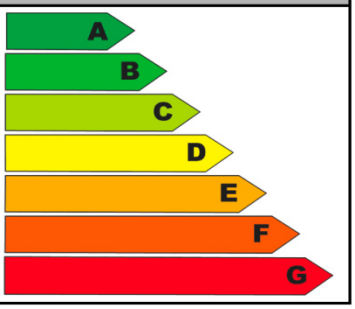
3.2.1.4. Energy rating of dwellings

The ability of dwellings to limit the energy demand for heating and cooling is assessed. The evaluation of quality is carried out at two levels: comparing the degree of fulfillment of limit values of the characteristic thermal parameters previously discussed and, comparing the energy demand of the dwellings that are the subject of study with that of a reference dwelling. The energy demand of the reference dwelling must be higher than that of the subject dwelling both in heating and cooling, to properly rate the energy quality of the dwelling.

The reference dwelling is defined as "that which has the same form, size, internal zoning and use as the subject dwelling. Also the building qualities of the facade, floor, roof and shadow elements equal the characteristic parameter limits for the climatic zone in which the dwelling is located". Its demand value corresponds to what is defined in this research as the optimal reference level for the purpose of evaluating energy quality and quality gaps by building type and territorial distribution in Chile.

The rating scale has seven levels defined in relation to the demand of the reference dwelling and ranges from level A (dwellings with low demand, lower than 55% of the reference) to level G (dwellings with higher demand, greater than 135% of the reference). In the following table, the scale and its concept are shown.

Table 3.17. Scale and concepts used for rating the energy quality of housing.

CALIFICACIÓN		CONCEPTO	
A	< 55%	Excelente	
B	55% ≤ De < 65%	Muy Bueno	
C	65% ≤ De < 85%	Bueno	
D	85% ≤ De < 95%	Moderadamente Bueno	
E	95% ≤ De < 110%	Base	
F	110% ≤ De < 135%	Malo	
G	135% ≤ De	Muy Malo	

Source: FONDEF project I D10 1025

3.2.2. Reference demands in different provinces of Chile

The reference demands are determined using the same criteria and methodology used to measure the energy quality of the supply of residential buildings in Chile, as explained in 3.1.1. The same sample is measured and

the same tools, climate databases and simulation criteria are used, with the exception that the thermal parameters of the envelopes correspond, in these cases, to the limit values defined in level E of the rating method.

Table 3.18 presents the energy demand references, by building typology in the cities of Antofagasta, Santiago, Concepción and Punta Arenas. Heating, cooling, and total energy demands are shown, taking into account the use of optimized thermal parameters of thermal transmission and airtightness. In addition, the table includes the values of airtightness and standardized infiltration of buildings and the weighted demands by province. The weighted indicator includes the participation, by built surface area, of the different types of building in the housing stock.

Table 3.18: Energy demand references for dwellings in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas.

Parámetro	PROVINCIA - TIPOLOGÍA																	
	Antofa		Santiago			Concepción							Punta Arenas					
	T6: VH2A	T7: VDHYL	T3: VAL2A	T6: VH2A	T7: VDHYL	T3: VAL2A	T6: VH2A	T7: VDHYL	T11: VM1A	T13:VM2A	T17:VFC2A	T19:VALM2A	T11: VM1A	T13:VM2A	T12:VM1P	T14:VM2P	17:VFC2A	T18:VFC2P
Inr	0,5	0,9	0,3	0,5	0,8	0,8	0,8	1,4	0,5	0,6	0,7	0,6	0,4	0,6	0,5	0,5	0,5	0,6
Ceir	9	16	14	16	32	33	34	32	25	27	32	24	33	45	40	37	44	53
Decr (kWh/m^2 año)	42	14	27	32	14	78	73	36	107	88	75	87	180	115	165	99	188	170
Derr (kWh/m^2 año)	30	11	38	48	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Dettr (kWh/m^2 año)	81	41	79	96	70	111	107	68	132	115	107	111	213	160	205	136	232	223
Detpr (kWh/m^2 año)	46		72			99							187					

Source: Created by the author

Inr : Reference standardized infiltration coefficient (1/h)
Ceir : Reference infiltration energy load (kWh/m2 year)
Derr : Reference cooling energy demand (kWh/m2 year)
Decr : Reference heating energy demand (kWh/m2 year)
Dettr : Reference total energy demand by building type (kWh/m2 year)
Detpr : Reference total weighted provincial energy demand (kWh/m2 year)

Table 3.19 presents the weighted provincial energy demands by built surface area of the main types of building present in the different provinces. In Figures 3.7 and 3.8, the demands are graphically illustrated in order to better appreciate the dispersions.

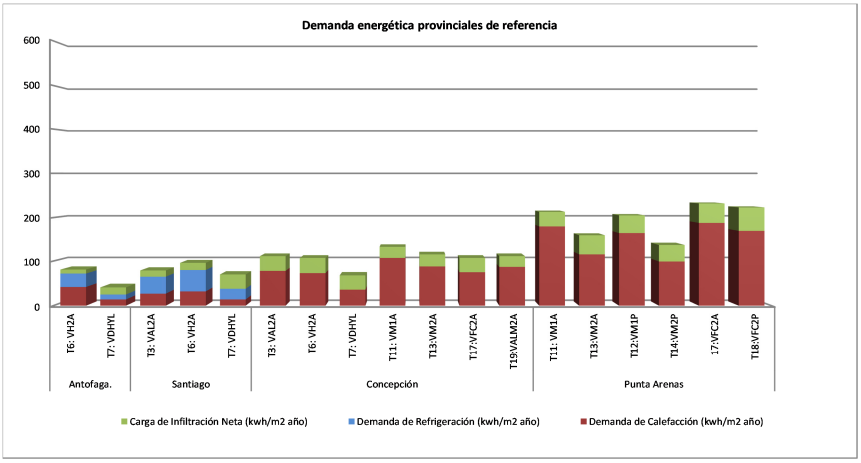


Figure 3.7: Energy demand references for dwellings in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas. Source: Created by the author

Table 3.19: Provincial energy demand references. Índices de hermeticidad y demandas ponderadas por superficie de tipos de construcción presentes en las provincias.

Localidad		Arica	Putre	Iquique	Pozo Almonte	Tocopilla	Calama	Antofagasta	Chañaral	Copiapó	Vallenar	Coquimbo	Ovalle	Illapel	La Ligua	Los Andes	San Felipe	Quillota	Valparaíso	San Antonio	Hanga Roa	Quillpué	Colina	Santiago	Puente Alto	San Bernardo	Melipilla	Talagante
Inr	(1/h)	2,0	0,5	0,6	0,7	2,0	1,0	0,8	2,4	0,5	0,2	0,7	1,3	0,3	0,4	1,0	0,6	0,4	1,1	0,8	2,0	0,7	0,3	0,7	0,4	0,4	0,5	0,5
Detpr	(kWh/m² año)	5	103	11	143	13	109	45	26	73	43	69	70	99	80	63	101	74	57	41	32	61	88	72	84	92	75	98
Decpr	(kWh/m² año)	0	103	0	143	0	105	21	25	9	33	69	61	89	62	41	86	59	57	68	1	61	65	55	61	74	54	81
Derpr	(kWh/m² año)	5	0	11	0	13	4	24	0	65	10	0	9	11	17	22	16	15	0	0	31	0	23	17	23	18	20	17

Localidad		Rancagua	San Fernando	Pichilemu	Curicó	Talca	Linares	Cauquenes	Chillán	Los Ángeles	Concepción	Lebu	Angol	Temuco	Valdivia	La Unión	Osorno	Puerto Montt	Castro	Chaitén	Coyhaique	Puerto Aysén	Chile Chico	Cochrane	Puerto Natales	Punta Arenas	Porvenir	Puerto Williams
Inr	(1/h)	0,9	1,1	0,5	1,4	0,4	0,7	0,4	0,3	0,7	0,7	0,7	0,3	0,3	0,2	0,3	0,7	0,7	0,7	0,6	0,7	1,6	1,0	0,6	0,5	0,6	0,5	1,1
Detpr	(kWh/m² año)	101	105	87	90	115	107	90	81	93	99	105	62	116	105	87	108	140	110	135	162	148	226	175	191	187	196	239
Decpr	(kWh/m² año)	93	97	87	84	106	97	76	72	86	99	105	54	116	105	87	108	140	97	135	162	148	226	175	191	187	196	239
Derpr	(kWh/m² año)	9	8	0	6	9	10	13	9	7	0	0	8	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0

Source: Created by the author

Inr : Reference standardized infiltration coefficient (1/h)
Detpr : Reference total weighted provincial energy demand (kWh/m2 year)
Decpr : Reference total weighted provincial heating demand (kWh/m 2 year)
Derpr : Reference weighted provincial cooling demand (kWh/m 2 year)

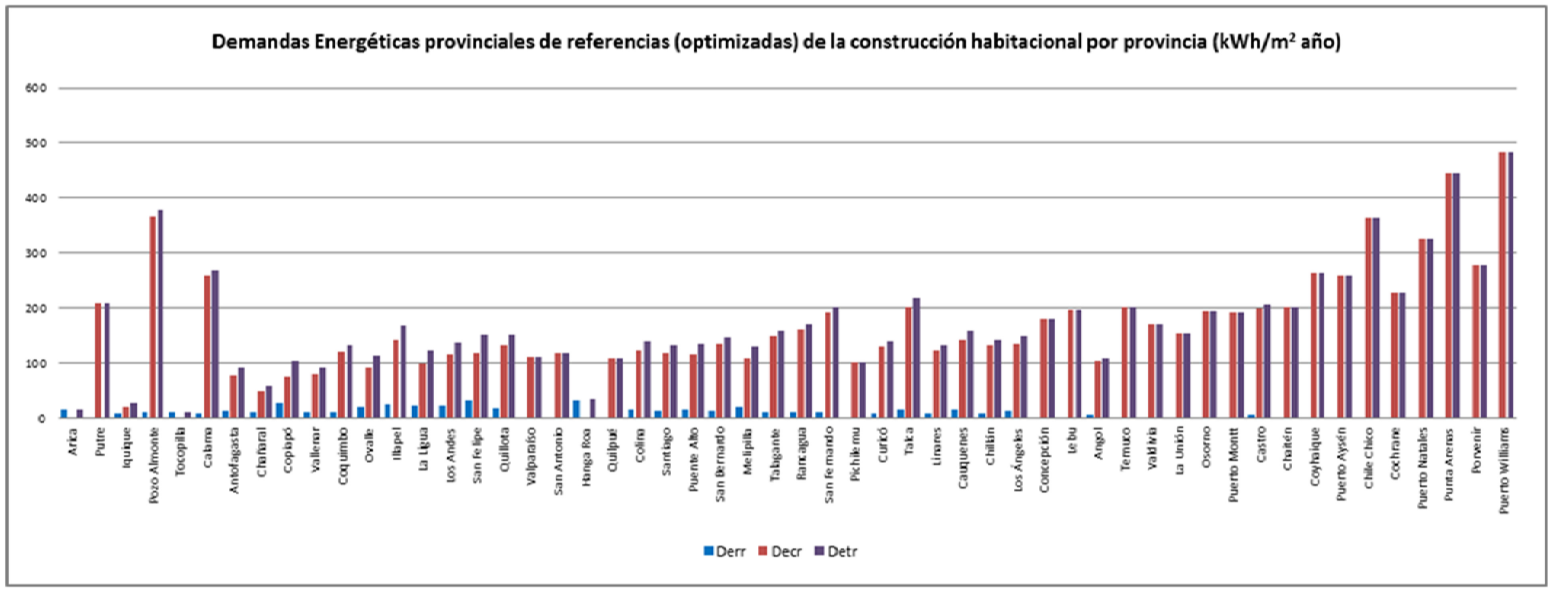


Figure 3.8: Provincial energy demand references in residential construction authorized in 2011 in the different provinces of Chile. Heating, cooling, and total energy demands.
Source: Created by the author

3.3. Identification of gaps and evaluations of quality.

3.3.1. Gaps by province

Table 3.20 presents the energy demands of the stock of new buildings authorized in 2011, comparatively by province, and the reference demands of the same stock. Also shown are the differences or gaps that result from comparing the current situation with the desirable or optimized one, in the terms that have been defined. In Figures 3.9, 3.10 and 3.11, the current and referential provincial demands are presented graphically and comparatively for cooling, heating and in total, respectively.

Figure 3.12 directly presents the quality gap associated with heating demand. It is of primary and great interest to reduce this gap in Chile. The existence of demand gaps is observed at the provincial level and, in consequence, of heterogeneous energy quality and different levels of importance. In absolute terms, the range of greater provincial heating demands in the national territory ranges between 0 and 259 kWh/m²year. This means that the supply of dwellings the market currently offers in Chile, depending on the building type and province of location, has higher energy demands within that range, with an average value per province of 74 kWh/m²year. These values are deemed to be important since they demonstrate the existence of residential buildings with very poor energy quality.

The differences or gaps are associated, strictly, with the outdoor climate variables in each province and the energy quality that the buildings in these provinces exhibit at present. The magnitude of gaps and their territorial distribution account for the degree of adjustment of the thermal protections against weather in the provinces. Thus, the dispersion of gaps between localities that are geographically very close, even within identical thermal

zones, shows the existence of regional microclimates. Such situations oblige the review, as has already been pointed out by discussing the current demands, of both the standards of thermal insulation and the territorial subdivision for the purposes of architectural design.

For purely purposes of analysis, at least four qualitative levels of gaps related to heating demand can be distinguished: very high, high, medium and low or zero.

At the first level, very high: there are gaps larger than 200 kWh/m² year. They are found in 3 of the 54 provinces, in cities such as Punta Arenas, Puerto Williams and Pozo Almonte. In the high range, from 150 to 50 kWh/m² year, are 38 of the 54 provinces, where more than 80% of the population is concentrated. At this level are cities such as Santiago (64 kWh/m² year); Concepción (81 kWh/m² year); Temuco (116 kWh/m² year); Valparaiso (54 kWh/m² year); Calama (154 kWh/m² year) and others. In the medium range of 50-10 kWh/m² year, are 10 of the 54 provinces. At this level, cities such as La Ligua, Vallenar and San Felipe can be found. Finally, in the low range of less than 10 KWh/m² year, are 3 provinces with almost non-existent heating demands. The cities of Arica, Tocopilla and Hanga Roa are located at this level.

In the range of minor gaps are mainly those localities in the northern area whose primary demands are related to cooling. In these localities, improving thermal insulation reduces heating requirements to nearly zero, but increases cooling needs in amounts that in absolute terms and measured by province are not deemed important. In all cases, the balance is positive; greater improvements could be achieved by increasing the requirements of solar protection and/or natural ventilation. There are not many incentives or it

does not seem justifiable to intervene in these localities to change the current requirements yet.

In the range of intermediate gaps are found localities throughout the country and, mainly in the north and central zones. In localities with a predominance of primary heating demands in the range 20-80 kWh/m²year, changing the standards and improving the energy efficiency of buildings can achieve savings between 30 and 50%.

In the range of high and very high gaps, are localities throughout the country and mainly in the central area, south of the country and Andean zone. In these localities, needs are almost exclusively for heating in the range 150 - 400 kWh/m² year. Modifying the standards and improving the energy efficiency of buildings in this stratum of localities can help to achieve savings between 40 and 60% approximately. Intervention is fully justified for the benefit of the population's quality of life and savings in energy use.

Cities such as Calama, San Fernando, San Felipe, Talca, Concepción and all the cities with a current weighted demand above 150 kWh/m²year should be part of a different zone than that where they are located. The standards of thermal protection need to be improved in provinces with quality gaps greater than 50 kWh/m² year and it is urgent to do so in all those provinces with heating demand gaps higher than 100 kWh/m²year, including the province of Santiago.

Table 3.20: Current provincial energy demands and references for the stock built in 2011 in Chile. Demands and gaps in heating, cooling and totals.

Localidad	Demanda actual Detp (kWh/m2 año)			Demanda referencia Detpr (kWh/m2 año)			Brechas (kWh/m2 año)		
	Calefacción	Refrigeración	Total	Calefacción	Refrigeración	Total	Calefacción	Refrigeración	Total
Arica	0	16	16	0	5	5	0	11	11
Putre	209	0	209	103	0	103	106	0	106
Iquique	20	9	28	0	11	11	20	-2	18
Pozo Almonte	367	10	378	143	0	143	224	10	234
Tocopilla	0	11	11	0	13	13	0	-2	-2
Calama	259	9	269	105	4	109	154	5	159
Antofagasta	79	14	93	21	24	45	58	-10	48
Chañaral	49	11	60	25	0	25	24	11	35
Copiapó	76	28	104	9	65	74	67	-37	30
Vallenar	81	11	92	33	10	43	48	1	49
Coquimbo	122	11	133	69	0	69	53	11	64
Ovalle	93	20	113	61	9	70	32	11	43
Illapel	143	26	168	89	11	100	54	15	69
La Ligua	100	23	124	62	17	79	38	6	44
Los Andes	116	22	138	41	22	63	75	0	75
San Felipe	119	33	152	86	16	102	33	17	50
Quillota	133	18	151	59	15	74	74	3	77
Valparaíso	111	0	111	57	0	57	54	0	54
San Antonio	119	0	119	68	0	68	51	0	51
Hanga Roa	1	33	35	1	31	32	0	2	2
Quilpué	110	0	110	61	0	61	49	0	49
Colina	124	16	140	65	23	88	59	-7	52
Santiago	119	14	133	55	17	72	64	-3	61
Puente Alto	117	17	134	51	23	74	66	-6	60
San Bernardo	134	14	148	74	18	92	60	-4	56
Melipilla	109	21	130	54	20	74	55	1	56
Talagante	149	10	160	81	17	98	68	-7	61
Rancagua	103	10	113	93	9	102	10	1	11
San Fernando	126	11	137	97	8	105	29	3	32
Pichilemu	96	0	96	87	0	87	9	0	9
Curicó	132	9	141	84	6	90	48	3	51
Talca	124	17	141	106	9	115	18	8	26
Linares	123	9	133	97	10	107	26	-1	25
Cauquenes	143	16	159	76	13	89	67	3	70
Chillán	133	9	142	72	9	81	61	0	61
Los Ángeles	136	14	150	86	7	93	50	7	57
Concepción	180	0	180	99	0	99	81	0	81
Lebu	197	0	197	105	0	105	92	0	92
Angol	104	6	110	54	8	62	50	-2	48
Temuco	202	0	202	116	0	116	86	0	86
Valdivia	170	0	171	105	0	105	65	0	65
La Unión	154	0	154	87	0	87	67	0	67
Osorno	195	0	195	108	0	108	87	0	87
Puerto Montt	192	0	192	140	0	140	52	0	52
Castro	199	7	207	97	13	110	102	-6	96
Chaitén	201	0	201	135	0	135	66	0	66
Coyhaique	264	0	264	162	0	162	102	0	102
Puerto Aysén	260	0	260	148	0	148	112	0	112
Chile Chico	364	0	364	226	0	226	138	0	138
Cochrane	227	0	227	175	0	175	52	0	52
Puerto Natales	325	0	325	191	0	191	134	0	134
Punta Arenas	446	0	446	187	0	187	259	0	259
Porvenir	277	0	277	196	0	196	81	0	81
Puerto Williams	484	0	484	239	0	239	245	0	245

Source: Created by the author

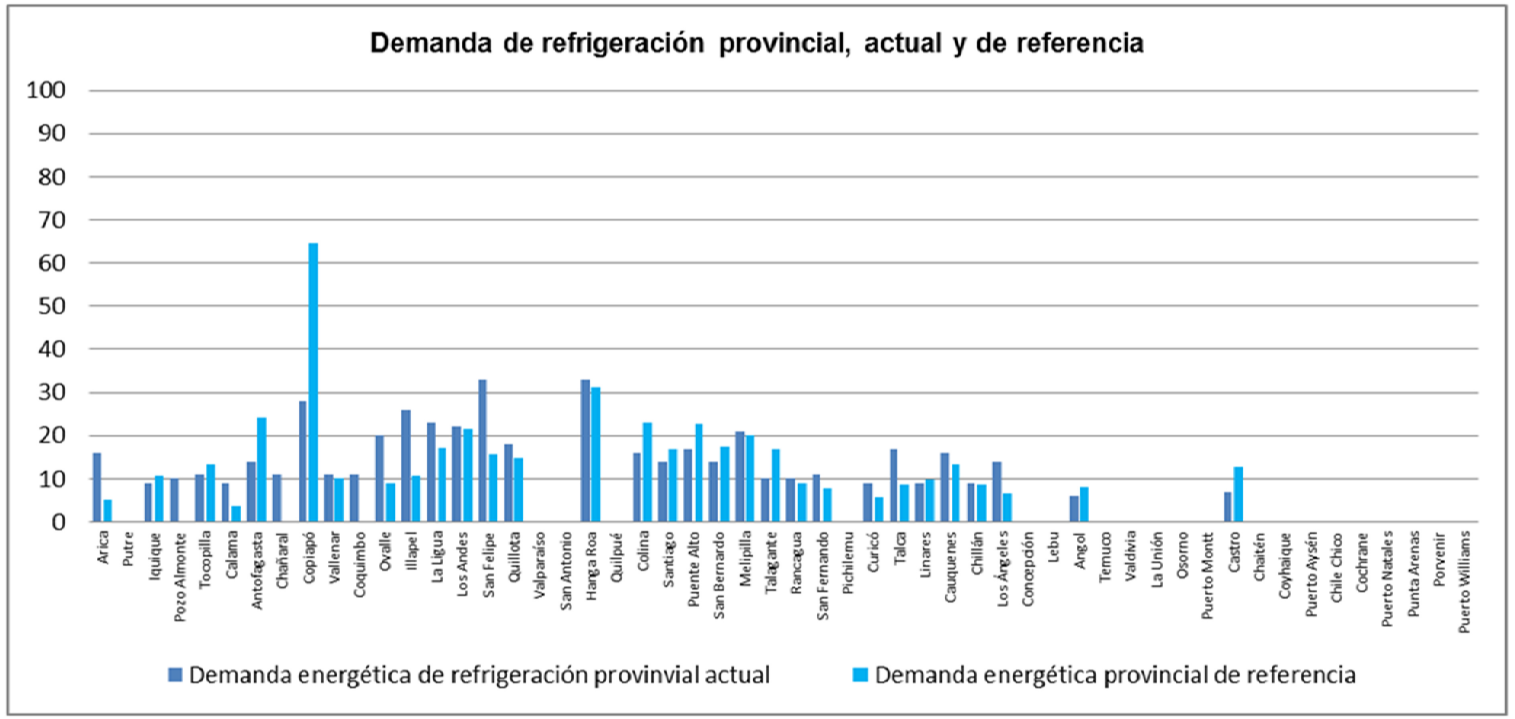


Figure 3.9: Current and referential (optimized) provincial cooling demands of building stock in 2011. Source: Created by the author

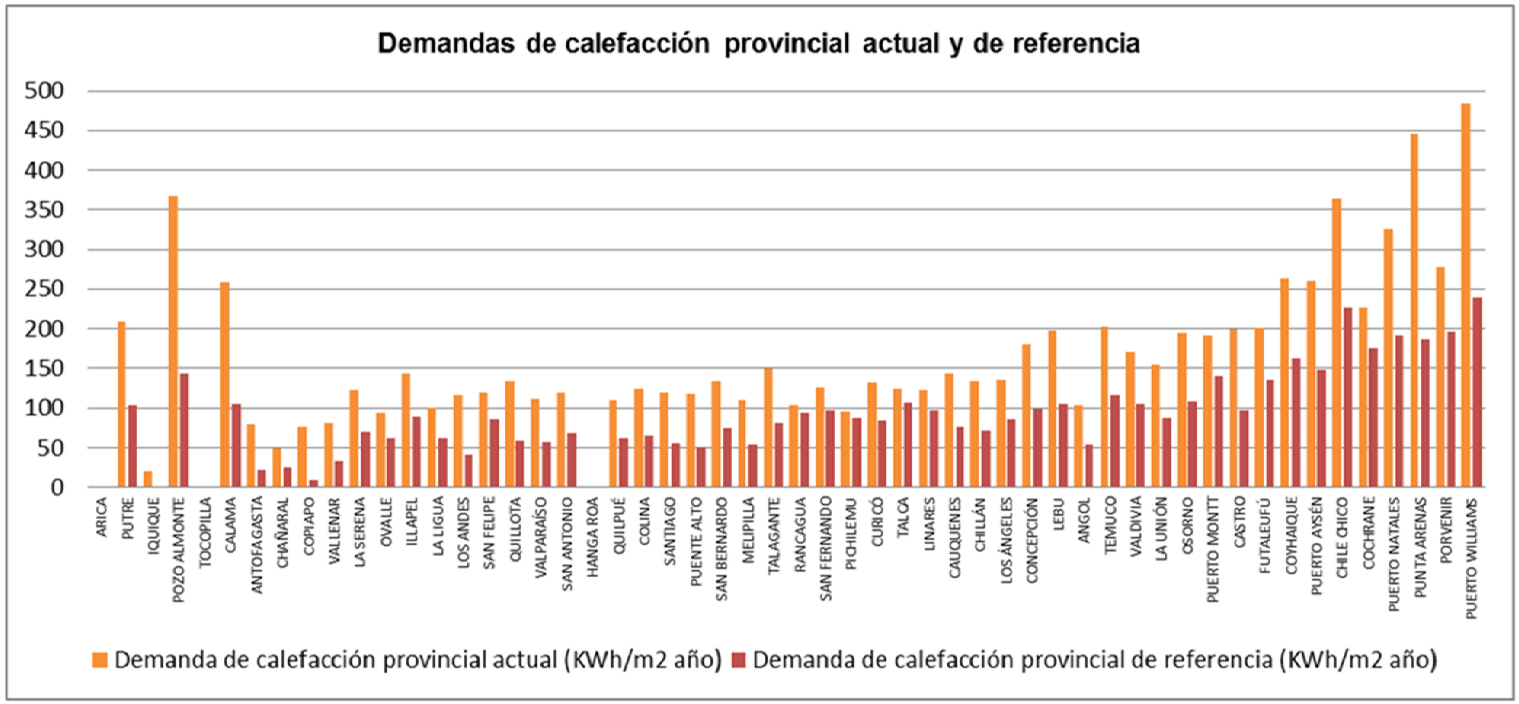


Figure 3.10: Current and referential (optimized) heating demands of building stock in 2011. Source: Created by the author

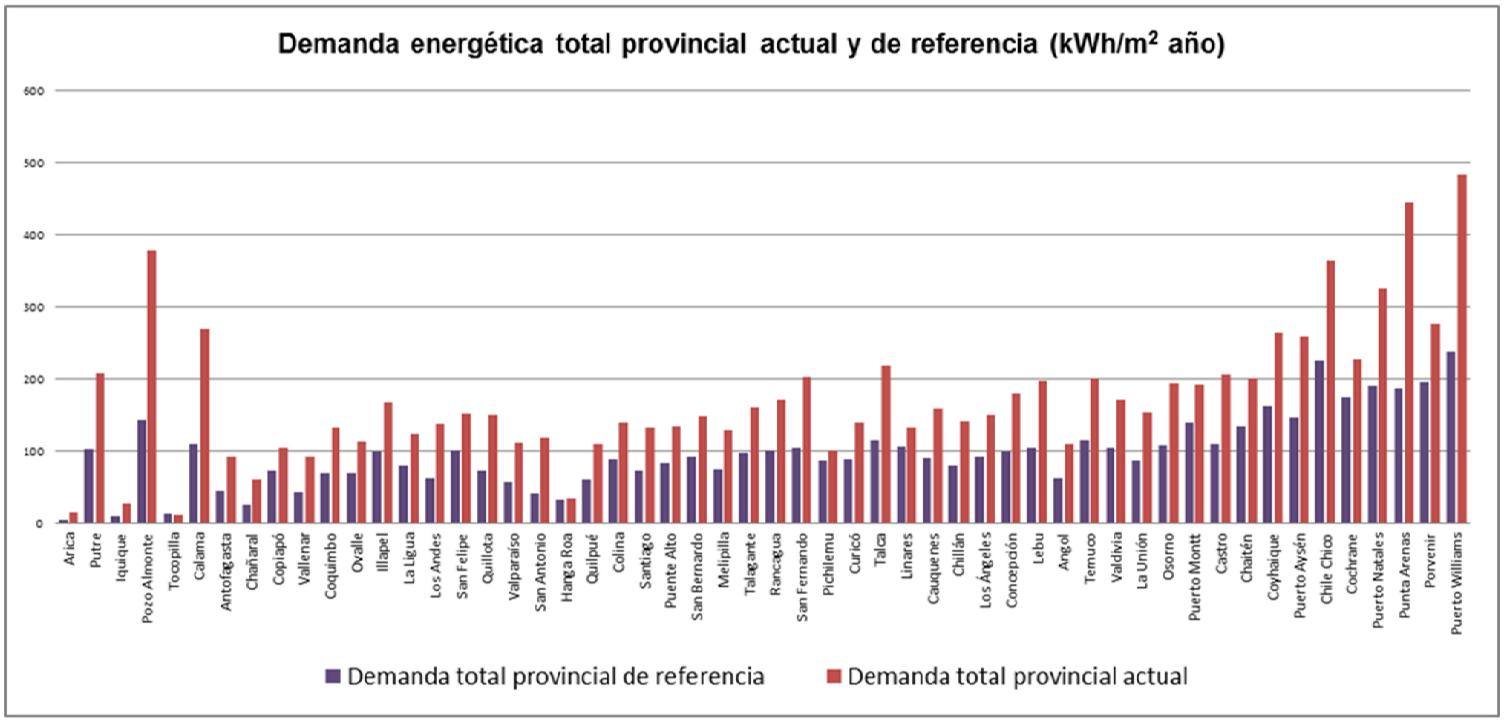


Figure 3.11: Current and referential (optimized) total demand of building stock in 2011. Source: Created by the author

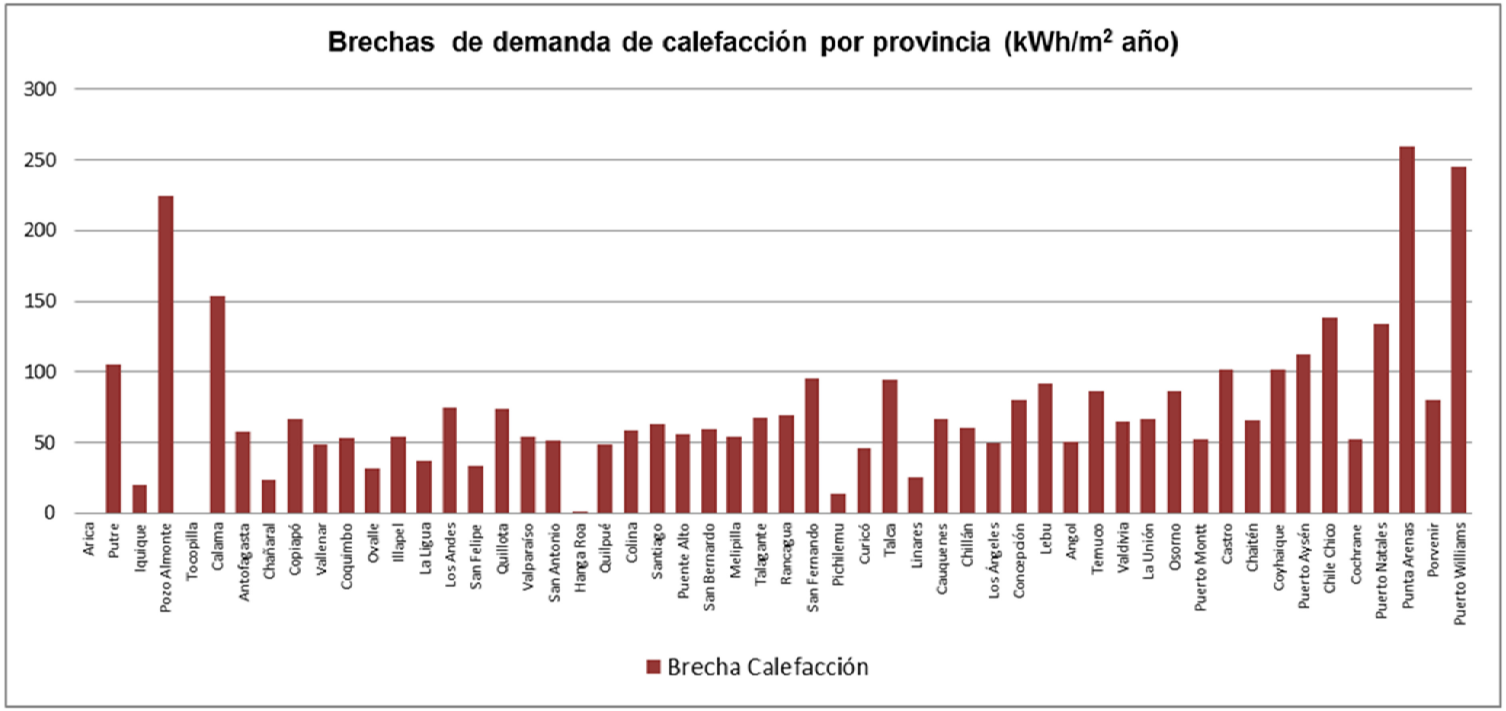


Figure 3.12: Quality gaps associated with heating **demands of building stock in 2011.** Source: Created by the author

3.3.2. Gaps by thermal zone and in the country as a whole

In Table 3.21, the energy demands of the new building stock authorized in 2011 are presented comparatively by climatic zone and the country as a whole, as well as the demands of the same reference stock. In addition, the differences or gaps that result from comparing the current situation with the desirable or optimized demand are indicated in terms that have been defined in this investigation. These differences correspond to demands in each thermal zone corrected with the authorized surface area in each zone in 2011.

Meanwhile, Table 3.22 presents current energy demands, optimized reference demands, with an infiltration value of 1 1/h, and the national total of the construction stock in 2011 in Chile.

The analysis of the sample as a whole shows that the reference sample represents a savings in heating of 47% compared to the sample under study. This means that all the constructions consulted to be built in 2011 in the 54 provinces of Chile, demand approximately twice the energy it would require if there existed thermal parameters better adjusted to the needs of each thermal zone, both in airtightness as well as heat transmission. The impact that policies oriented to the effective improvement of the construction stock in Chile could have is esteemed to be important. All precedents should be taken into account to study both the policies of thermal reconditioning as well as the requirements of standards of thermal insulation and airtightness of residential construction in Chile.

The specific analysis of the sample by thermal zone also generates interesting results, even though there are limitations considering the fact that for the purposes of this analysis, provinces with not-so-homogeneous

features have been grouped within the zones. It can be deduced that, although the greater energy reductions by construction type are obtained in the extreme southern areas, the major impacts on reduction in demand of the stock are achieved in thermal areas 3 and 4, in relatively less rigorous climates. The larger construction volumes in those areas explain this situation. Consequently, at the national level major impacts in the reduction of heating costs in future new constructions could be achieved by modifying the standards of thermal protection for the first zones of the northern and central parts of the country.

When comparing the references of energy demands for heating of the building stock in 2011, it can be deduced that in global terms, the energy demand is underestimated by 15%, when standardized infiltrations equal to 1 1/h are considered. In cases where the standardized infiltrations are greater than one, that is, in 40 of the 54 provinces, the total energy demands by province are higher, between 20 and 50%. In the remaining provinces, where standardized infiltrations are less than 1 air renewal, the provincial demands are 5% lower on average.

Table 3.21: Current energy demands and reference demands by thermal zones and national total of the construction stock in 2011 in Chile, weighted by built surface area by province.

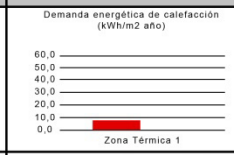
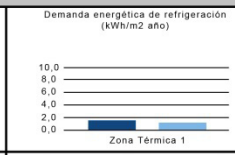
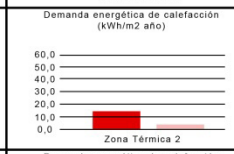
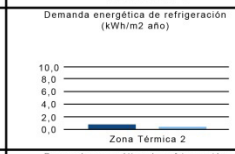
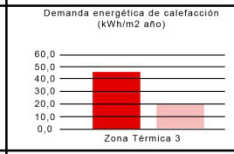
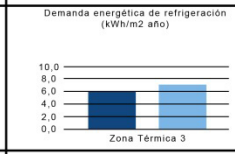
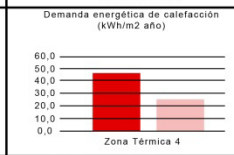
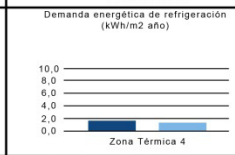
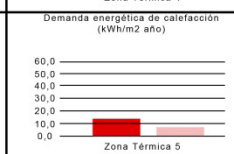
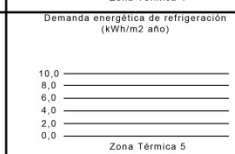
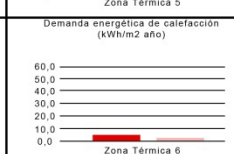
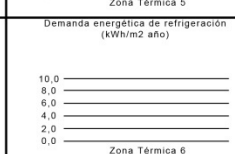
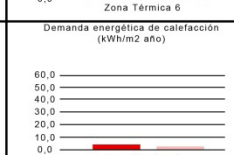
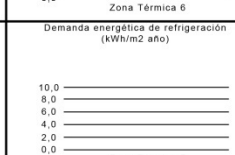
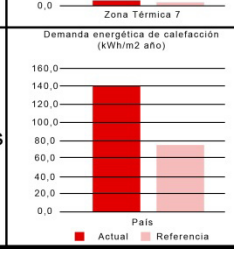
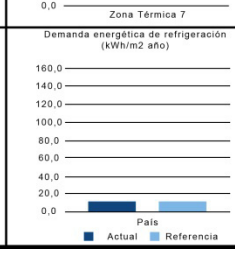
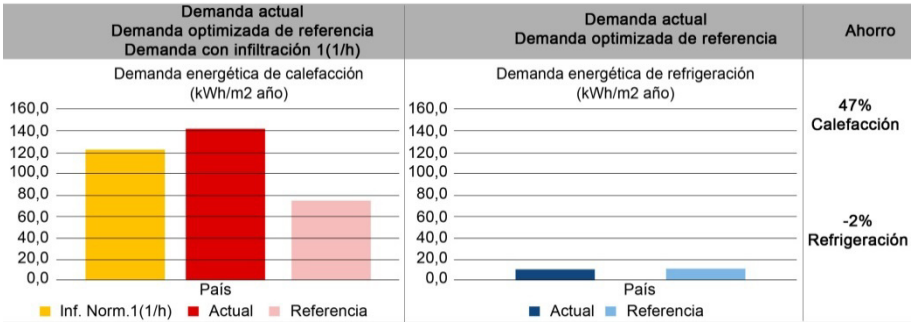
ZT	Demanda Actual/Demanda de Referencia		Ahorro	
			Calefacción	Refrigeración
1			58%	-5%
2			49%	41%
3			49%	-19%
4			43%	28%
5			42%	0%
6			34%	0%
7			48%	0%
País			47%	-2%

Table 3.22: Current energy demands, optimized reference demands and with infiltration 1 1 1/h, national total of the construction stock in 2011 in Chile, weighted by built surface area by province



Source: Created by the author

3.4. Chapter 3 conclusions

The comments on and conclusions of the diagnostic of the energy quality of the stock of new buildings in Chile is summarized as follows:

The baseline of energy quality in the stock of new residential constructions in Chile was determined through the evaluation of representative samples of the housing stock built in 2011 in the 54 provincial capitals of the country. Quality gaps have been established by building type, by province, thermal zone and national total. For the first time, this study was carried out in Chile considering the real airtightness characteristics of the building stock. Its results deliver the most precise estimation up to now in Chile, of the thermal quality of housing and of the territorial distribution of quality.

It is concluded that, in general terms, the residential buildings suffer from deficient thermal protection. The standards of thermal insulation and airtightness in the buildings are low and very low in most parts of the country. The residential building stock registered in 2011 demands approximately twice as much energy for heating than the strictly necessary

amount. Both the thermal zoning used and standards of requirements do not seem to fit the needs of optimal minimum energy use and need to be modified. The quality levels that mass housing construction exhibits in Chile are not up to the current demands of modern societies, not at least at the country's present level of economic and technological development.

Hence, the development and progress of the country on various fronts are questioned. What can explain these gaps in quality?

There are basically three hypotheses of the causes, which will be addressed following this diagnostic presentation, namely: (1) The investigation leading to the development of new and better solutions in materials, construction elements and buildings has not known how to respond to industry and societal needs; (2) The regulatory framework is weak and has not served for the purposes of optimizing energy use in the building sector. Limitations in its scope and performance criteria prevent its better contribution and; (3) The laboratory infrastructure and tools available in the country to support the processes of innovation and development, the application of standards and regulations, and training, is insufficient or unsuitable for the current development needs.

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4.0. EVOLUTION AND CURRENT STATE OF DEVELOPMENT RESEARCH IN CHILE

This chapter presents and discusses the research and development work carried out in Chile in the last three decades concerning energy and environmental improvement in housing. The political and institutional framework that supports the research activity in Chile is presented together with the results of a cadastre of the most relevant research and technological development projects executed during the 1985-2012 period in relation to the topic. Areas of work, objectives, type of innovation, level of development and results are identified, among others. Finally, a technical characterization is presented of the main construction systems used for building dwellings on the housing market in Chile. The chapter concludes with an analysis regarding how research and development needs have changed, how they have been dealt with, and the results and deficits in these matters, taking into account the diagnosis of energy quality of the new housing stock reported in chapter 3 of this report.

4.1. Political-institutional framework

The Chilean System of Science, Technology and Innovation is led by the Presidency of the Republic, with direct counsel of the National Innovation Council for Competitiveness (CNIC). This Council's mission is to advise the President of the Republic on the identification, formulation and implementation of policies and actions that strengthen innovation and competitiveness as key elements for the development of the country. There is also a Committee of Secretaries for Innovation, made up of seven Secretaries of State, which has the mission of defining and implementing,

through various programs and instruments, the short, medium and long-term national policies on matters of science, technology and innovation. These three entities are the main political actors in Chile's Innovation System, which is in charge of formulating and approving the policies and activities leading to their implementation.

The Council of Secretaries is composed of the Secretaries of Housing, Foreign Affairs, Education, Public Works, Transportation and Telecommunications. The departments with most influence and participation in the national innovation system are Economy and Education. Within these departments are found respectively, the Chilean Economic Development Agency (CORFO) and the National Commission for Scientific and Technological Research (CONICYT), the principal institutions that manage and administer instruments and resources directly targeted at strengthening the national innovation system.

CORFO mainly operates in the field of business innovation and is oriented towards meeting initiatives proposed by companies and individuals that contribute to the management and generation of processes of innovation, technological change, entrepreneurship and new business creation in the national productive sector. On the other hand, CONICYT is focused on the area of basic and applied research with development purposes, and attends to initiatives proposed by Universities and Research Centers with demonstrable capabilities in research and development. Both CORFO and CONICYT jointly finance research projects proposed through competitive funds, whose allocation rates according to fund type range between 10 and 30%, approximately.

The System of Science, Technology and Innovation, which is directly related to the construction sector in Chile, is made up of the policy-makers and

techniques indicated, companies in the sector, public and private R&D institutions, national and foreign higher education institutions and, nongovernmental organizations that carry out R&D activities, among others.

Figure 4.1 summarizes the system that mainly applies to the development of research in the area of housing.

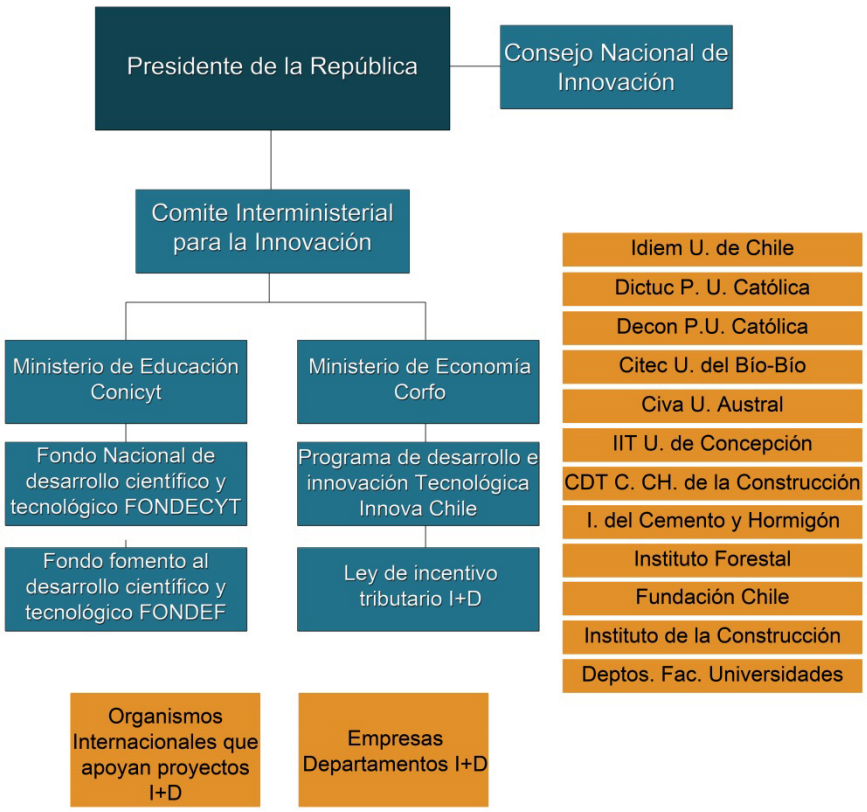


Figure 4.1: System of science, technology and innovation, linked to the construction industry in Chile. Main instruments and political agents, managers and executors of R&D work associated with the development of residential construction.
Source: Created by the author with data from CONICYT.

Below are described the main bodies, instruments and national government programs in science, technology and innovation, related to the reported activity.

4.2. Organizations and Programs

4.2.1. National Commission for Scientific and Technological Research (CONICYT)

Created in 1967 as an advisory body to the Presidency on matters of scientific development, it focuses on two major objectives or strategic pillars: the promotion of the formation of human capital and the strengthening of the country's scientific and technological base. It states that its mission is: "To promote the formation of human capital and promote, develop and disseminate scientific and technological research in consistency with the National Innovation Strategy, in order to contribute to the economic, social and cultural development of Chileans, through the provision of resources for competitive funds; creation of opportunities for coordination and connection; design of strategies and execution of awareness-raising activities with citizens; promotion of better access to scientific- technological information, promotion of a regulatory framework that safeguards the proper development of science, technology and innovation."

Currently, CONICYT administers the two principal competitive funds for the development of basic and applied research activities: The National Fund for Scientific and Technological Development, FONDECYT, and the Fund to Promote Scientific and Technological Development, FONDEF.

The National Fund for Scientific and Technological Development (FONDECYT), is a public program designed to stimulate and promote the development of basic scientific research in the country. It was created in 1981 and started the system of competitive funds introduced by the Chilean State as a criterion for the allocation of resources in the areas of Higher

Education and Scientific and Technological Development. Its mission is to stimulate and promote the development of basic scientific and technological research in the country. Consequently, it encourages initiatives put forth by individuals and groups of researchers by funding research projects of excellence, without distinguishing disciplines or institutional origin, starting with efficient management and based on permanent relation with and enrichment of their individual, collective and institutional users (Fondecyt, 2014).

Fondecyt, through the funding of research projects, has led to the consolidation of scientific activity in the country by providing it with a critical mass increasingly more specialized in different areas of knowledge; scientific and technological infrastructure; connected networks of researchers and scientific-technological knowledge compatible with the levels of social-economic development achieved by Chile.

Fondecyt's 2014 budget reaches 101,673 million pesos and is intended to finance new projects and those in progress. This amount is equivalent to 37.4% of CONICYT's budget for its different programs. These programs are financed through Fondecyt basic research projects, and applied research projects to a lesser degree. They are oriented towards the development of general knowledge, without distinguishing areas or disciplines. The participation of companies is not required, as is the case in all other funds.

In the 2011 regular contest for funds, the Fondecyt resources were assigned to the financing of projects in the following disciplines: biology (24.4%); medicine (16.3%); engineering (10.6%); chemistry (8.4 %); physics and astronomy (5.7%); agronomy (6.5%); mathematics (4.4%); others (23.7%). Included in 'others', architecture, urban planning, demography, geography,

and art were given 2.6% of the funds. There is a greater inclination in this line for projects in the areas of natural, exact and biological sciences.

The Fund to Promote Scientific and Technological Development (FONDEF), is a public program created in 1991. Its purpose is to increase the competitiveness of the national economy and improve Chileans' quality of life, by promoting the link between research institutions, companies and other entities through the realization of applied research and technological development projects of interest to the productive and public sectors . Projects apply for funding through a competitive system, to which higher education institutions and research centers apply (Fondef, 2014).

The budget of Fondef for 2014 reaches 18,961 million pesos and is intended to finance new projects and those in progress. This amount is equivalent to 6.9% of CONICYT 's budget for its various programs. Fondef finances applied and to a lesser degree developmental research projects, which are oriented towards the development of general knowledge in thematic areas prioritized by region and/or country. It requires the participation and economic contribution of public and private companies and institutions.

The main thematic areas addressed through the Fondef program combine three basic criteria: those that have been the traditional basis of the Chilean economy (mining, forestry, fishery and aquaculture); those that are highly dynamic in the creation of value (ICT and manufacturing); and those of high social impact (health, education, water and energy). The incorporation of other areas that meet these criteria is under constant study.

4.2.2. Chilean Economic Development Agency (CORFO)

Created in 1939, it is the Chilean government agency responsible for implementing government policies in the field of entrepreneurship and innovation, through tools and instruments that are compatible with the central elements of a social market economy. The agency's mission is: "To promote entrepreneurship, innovation and competitiveness with an eye to improving Chile's productivity, and to achieve globally competitive leadership positions." This entity operates in the field of innovation and entrepreneurship of individuals and institutions and/or companies with the aim of integrating new projects into the national and even international market, which enable achievement of leadership positions.

Currently, CORFO has more than 70 financing systems, divided in 5 areas of action: innovation and technological development, modernization of companies that associate themselves to compete, improvement of businesses management, financing and development of financial instruments to meet the needs of companies, and the productive development of regional and emerging sectors. It has offices throughout Chile and is organized on the basis of four business divisions: Management of Innovation, Management of Entrepreneurship, Management of Competitiveness, and Management of Investment and Financing. Nowadays, it focuses its action on the promotion of entrepreneurship, innovation and the competitiveness of micro-, small- and medium-sized enterprises.

CORFO administers the two major competitive funds for financing initiatives leading to technological innovations and business ventures: the INNOVA CHILE Program and the Tax Incentive Program for Private Investment in Research and Development.

INNOVA CHILE Program: It is a public program created in 2005 with the mission of promoting and facilitating innovation in businesses, encouraging the entrepreneurial development and strengthening the national system of innovation. Among its objectives are: to support the development of businesses that generate high economic and social impact, to promote the values of innovation and to facilitate access to world-class tools in order to promote the installation of practices that favor innovation and entrepreneurship (Innova, 2014).

The Innova program resulted from the merger of two previous programs created in 1991: the Fund for Development and Technology Transfer (FONTEC), and the Fund for Development and Innovation (FDI). These were pioneering programs in Chile in terms of allocating public resources for the promotion of research activities, development and technology transfer, innovation and entrepreneurship. They were created to strengthen the new role assumed by CORFO in the mid-nineties, when it ceased to act as a lending entity and began to devote greater efforts to the promotion of innovation and the creation of public entities dedicated to technological research with productive applications.

This program was created to strengthen the commercial transfer of R&D, which is still recognized as very low. During the first decade of this century, the country invested significant resources in research and development at universities and technological centers; this investment enabled the generation of a significant flow of high-level publications, estimated at more than 6,000 ISI articles in 2010, but a very low level of patenting, less than 50 patents that same year and no more than 10 cases of new businesses resulting from research work (Corfo, 2012).

The 2014 Innova budget reached USD $10 million dollars, destined to finance new projects and those in progress; this amount is equivalent to 2.4% of CORFO's budget for its various programs.

Through Innova Corfo, projects are financed in areas defined as priority by the different regions of the country; this can be explained due the fact that a portion of the funding comes from the Innovation Fund for Competitiveness with Regional Allocation, which is decided upon by the Regional Governments. In the Biobío Region, for example, food, forestry, timber and energy are areas of priority interest.

4.2.3. Tax incentive program for R&D

Incentive program for private investment in research and development (R&D) in Chilean organizations: Law number 20.241 of January 20, 2008 and modified in June 2012. This law allows the lowering, through taxes, up to 35% of the resources devoted to R&D activities, carried out either with their own capacities or with third party support, as well as those recruited to a specialized center on the Corfo Register. In addition, the remaining 65% of the amount invested may be considered as a necessary expense to produce income (Corfo, 2014).

The aim of this law is to reduce the gap in private spending on R&D, which is relatively low in Chile. Private spending in Chile represents approximately 40% of the total in comparison to the average of 65% in OECD countries (OECD, 2013).

From 2008 to March of 2014, a total of 136 requests for certification of the R&D Law have been certified, for a total amount of USD $50 million. The state does not directly provide resources since it is a matter of tax benefits;

35% corresponds to tax credit against first category taxes, which is understood as the indirect contribution of the state for the tax credit.

4.3. Institutions implementing and managing R&D

4.3.1. Institute for Research and Testing of Materials at the University of Chile, IDIEM U. of Chile

It is the oldest of the research centers in the field. It is an institution that is dependent on the Faculty of Physical and Mathematical Sciences at the University of Chile. It was founded in 1898 as a Workshop on Material Resistance and is dependent on the School of Engineering at the University of Chile. It has as its main objective to test and verify the quality of the materials to be used in the construction of public works. In this way it became the first Technical Control Laboratory for Materials to exist in the country.

This organization has offices throughout the nation and covers a wide area of specialties to which it provides various services in engineering, materials testing and elements, including technical inspection and quality certifications. It covers the areas of technical inspection of residential construction projects and, control and testing of materials in the areas of habitability and conditioning. It has modern laboratories specialized in thermal, acoustic and fire research. It is part of the Official Register of Technical Control Laboratories for Construction Quality in Concretes, Soils, Asphalts, Elements and Components, and Environmental Conditioning, among others, in agreement with the Supreme Decree No. 10 of the Ministry of Housing and Urban Development of 2002 http://www.idiem.uchile.cl/

4.3.2. The Directorate of Research in Science and Technology at the Catholic University of Chile, DICTUC UC:

It is a subsidiary company of the Pontifical Catholic University of Chile, which provides engineering services through their various areas of specialization. It was founded in 1938 to transfer the expert knowledge generated at the UC School of Engineering and to use this knowledge to serve the community with concrete solutions to its needs. Its mission is defined as: "To seek and implement new ways of transferring knowledge generated within academia, through mechanisms that accelerate its use for the service of the community.

The main areas of work of this institution are: Consulting in Engineering and technological development, which delivers services in relevant diverse areas such as sustainable energy, food, water, soil or demand studies, among others, and; certification and laboratory services, dedicated to quality management and certification of different materials and procedures. This work is done through business units (areas and centers) of DICTUC, that cover all the specialties of UC Engineering, under the leadership and supervision of professors or of an academic department of UC Engineering.

This organization has offices throughout the nation. It covers the areas of technical inspection of residential construction projects, and control and testing of materials in the areas of habitability and refurbishing. It has laboratories specialized in thermal and fire research. Is part of the Official Register of Technical Control Laboratories for Construction Quality in Concretes, Soils, Asphalts, Elements and Components, and Environmental Conditioning, among others, in agreement with the Supreme Decree No. 10 of the Ministry of Housing and Urban Development of 2002. http://www.dictuc.cl/

4.3.3. The Directorate of Outreach in Construction at the Catholic University of Chile, DECON UC:

It belongs to the School of Civil Construction at the Pontifical Catholic University of Chile. This organization operates as a link between the academic activities of the School and the scientific and technological needs of the various productive sectors and services of the country.

The main areas of work of this institution are: the Division of Laboratory and Certification, which is dedicated to the provision of laboratory services and certification of aggregates, concretes, soil mechanics, asphalts, pre-cast elements, physicochemical tests, construction physics and others, and; the Division Consultancy and Studies, in which services are provided in the areas of management and quality control, strategic planning, project planning and control, integrated project management and studies for the subsidized housing sector, among others.

This organization has offices in a large part of the country. It covers the areas of technical inspection of residential construction projects, management and quality control. It is in the process of constructing laboratories to cover the area of environmental conditioning. Currently, it is part of the Official Register of Technical Control Laboratories for Construction Quality in the areas of technical control of concrete, soil and asphalts. http://www6.uc.cl/decon/site/edic/base/port/pagLaboratorios.php

4.3.4. The Center for Research in Construction Technologies at the University of the Bío-Bío, CITEC UBB:

It is a organization devoted to the development and transfer of technology at the University of the Bío-Bío, which was established in the year 2008. It defines as its mission: "to develop, apply and transfer knowledge and UBB technology to the national construction industry and the Chilean community in general; to respond with excellence and quality to their needs for consulting, human resources training, applied research and innovation". http://www.citecubb.cl/web/

The core idea at CITEC UBB is sustainable architecture and construction. Its main areas of work are: physics of construction, building systems and processes, sustainable architecture and construction, energy efficiency, structural engineering and technical inspection of construction projects. It develops research and development services aimed at the product/process development of new products and/or services applicable in local building: consulting services; studies and technical inspections in the areas of design, quality management and building projects; services in testing and evaluation of the performance of materials, elements and constructions; services for the education and training of personnel through work in support of pre- and post-graduate education, and personnel training for companies in the sector, which is conducted by the University of the Bío-Bío.

CITEC UBB is located in the Biobío Region and primarily covers the needs of country's south-central zone. It focuses on more specific areas of work; it covers the areas of technical inspection of residential construction projects and control and testing of materials in the areas of habitability and conditioning. It has modern laboratories specialized in thermal, acoustic and hygrothermal areas. It is part of the Official Register of Technical Control

Laboratories for Construction Quality, in Concretes, Soils, Asphalts, Elements and Components, and Environmental Conditioning, among others, in agreement with the Supreme Decree No. 10 of the Ministry of Housing and Urban Development of 2002.[8]

4.3.5. The Center for Research on Southern Housing at Austral University, CIVA:

Belonging to Austral University of Chile, it is an organization dedicated to the certification and investigation of all the processes related to the construction of dwellings. The primary objectives of its work is: "To put at the service of the community the knowledge gained in the field of housing, in the southern zone of Chile, verifying in a neutral, scientific and technical manner, the methods used within the construction" http://www.civa.cl/ .

The services delivered by CIVA include: certification of housing quality, certification of thermal envelopes, quality control of prefabricated structures, technical inspection of works, training, expert witnesses and non-destructive testing. It focuses primarily on consulting and and quality control work. It has acoustics laboratories and is not a part of the Ministry of Housing's Official Register of Technical Control Laboratories for Construction Quality.

[8] CITEC UBB is the result of the natural evolution of a research group which started its activities in 1980s. Its main focus is the R&D activities which represent nearly 70% of its work. It was formed as a Center in the year 2008, through a contest for the creation of R&D centers in Chile, the first competition of its kind in the country. Innova Corfo project Number 06Cof1IXC-56 won and was selected, with this author as its director and project head. Since its inception he has served as a researcher and the director in charge for the superior authority of the University of the Bío-Bío and the Chilean Economic Development Agency, Corfo, Chile. CITEC UBB is part of Corfo's register of Research Centers.

4.3.6. The Technological Research Institute at the University of Concepción, IIT:

The IIT works as a liaison between the Faculty of Engineering and the external environment dependent on the dean's office. The goal of this organization is to promote, coordinate and administer the provision of services to third parties in the field of research and technology transfer, technical assistance and continuing education. http://www.iit.udec.cl/

As part of its technical assistance and technology transfer services, the IIT conducts projects that include activities, whose objective is to search for appropriate solutions to the problems or needs of the organizations. Included within these are: technological innovation projects, design of equipment and components, development of processes, special engineering projects, various studies, diagnoses, consultancy, etc. It is mainly concentrated on engineering services that support the industry in general, with a specific line of support for the construction industry through an energy simulation laboratory. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality

4.3.7. The Technological Development Corporation of the Chilean Chamber of Construction, CDT:

It is a private corporation created by the Chilean Chamber of Construction in 1989. Its main objective is "to promote innovation, technological development and the productivity of companies in the construction sector, through various service areas such as technological dissemination, knowledge management, sectoral studies, coordination of technological

interest groups and technology transfer". It is the primary agent of its kind in Chile and is present throughout the nation. www.cdt.cl

Its main areas of development are: Productivity, performing management services and the development of solutions that address different needs of the construction and mining industries; innovation, where projects are formulated by maintaining a constant exchange of information with the companies of the sector; sustainability, providing consulting services for the transfer of knowledge and for the implementation of real estate projects; research and studies on matters of sustainable construction and energy efficiency and an area of information and technology outreach, using a virtual platform of technical specifications for construction called especificar.cl.

By nature, it concentrates mainly on management tasks and technology outreach for its partners. Its work in research and technological development is usually carried out in association with universities and research centers. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality.

4.3.8. The Chilean Cement and Concrete Institute, ICH:

It is a private, non-profit corporation, created with the goal of promoting new, appropriate, better and increased uses of cement and concrete in their diverse applications, through technological development and dissemination of good use practices. The main industries in the country linked to the production and use of cement in Chile participate in the ICH. http://ich.cl

The activities carried out by the ICH include conducting training courses, seminars, and various outreach activities for the promotion of new technologies related to these materials. It delves into research and technological development projects associated with universities and research centers. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality.

4.3.9. The Forest Institute of Chile, INFOR:

It was established as a private corporation, under the Ministry of Agriculture. Its mission is: to create and transfer scientific-technological knowledge of excellence for the sustainable use of resources and forest ecosystems, the development of derived products and services; as well as to generate relevant information for the forestry sector in the economic, social and environmental areas. http://www.infor.cl/

It covers six research areas defined by the INFOR, established by both the Government and according to its mission and vision: Support for small and medium forestry enterprises and sawmills; information and strategic forestry analysis; handling and recovery of native forest; conservation and genetic improvement; continuous forest inventory; climate change and water.

It is linked to residential construction through its research work for the promotion of the use of wood in construction. It delves into research and technological development projects associated with universities and research centers. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality.

4.3.10. The Chile Foundation, FCh:

It is a private, non-profit corporation established in 1976, whose partners are the Chilean Government and BHP Billiton-Minera Escondida. Its mission is: "to introduce high impact innovations and enhance human capital to increase the competitiveness of Chile, promoting and developing the economy through technology transfers and in partnership with local and global knowledge networks." http://www.fundacionchile.com/

The main areas of development at FCh are: food and biotechnology, aquaculture, water and environment, energy and climate change, human capital, education and digitization. It uses a recognized open innovation model that considers the implementation of projects up to commercial exploitation phases, which makes it possible for the solutions to be translated into tangible products on the market. It is linked to housing construction through its research work for the promotion of the use of wood in construction and efficient energy use. It delves into research and technological development projects associated with universities and research centers. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality.

4.3.11. The Chilean Construction Institute, IC:

It is a private, non-profit corporation created in the year 1996 by the major public and private institutions related with the construction sector and currently has 23 partners. The mission of the IC is to "identify, negotiate, promote and coordinate initiatives to improve the competitiveness of national construction". http://www.iconstruccion.cl/

The IC is actively involved in the development of standards and amendments to the General Ordinance on Urban Planning and Constructions, and in the development and administration of records of specialties. The projects and initiatives that the Construction Institute deals with are approved each year by the Board of Directors and defined in the Board's Action Plan for that period. In general terms, the projects or tasks must be transverse and have sectoral importance.

It is linked to residential construction through its research work for the creation and/or adaptation of norms governing the construction of dwellings and efficient energy use in the buildings sector. It delves into research and technological development projects associated with universities and research centers. In does not have laboratory infrastructure with official recognition by the Ministry of Housing as Technical Control Laboratories for Construction Quality.

Of the Centers mentioned above, currently IDIEM, DICTUC, CITEC UBB, Chile Foundation, IIT and INFOR are part of the Official Public Register of Research Centers administered by the Chilean Economic Development Agency, CORFO. This Register recognizes in these organizations, the existence of installed capacities to carry out research and development (R&D) activities, in the framework of the Tax Incentives for Private Investment in R&D Law.

4.4. Companies dedicated to R&D tasks

In this category are found companies related to the building of dwellings, buildings for residential and non-residential purposes or public buildings (hospitals, offices, schools, commercial establishments, etc.); and, companies that act as producers and providers of supplies to the construction

sector such as materials, construction elements and engineering services, consultancy and others. The Chilean Chamber of Construction records declare 724 registered companies as partners in Santiago and at the Technological Development Corporation (CDT), of the same subsidiary, there is a record of 603 businesses certified under various international and national standards (ISO 9001, ISO 14001, OHSAS 18001 Occupational Health and Safety, National Award for quality, Risk Prevention 4.5 and 6 stars, NCh 2909) with very different levels of technological development.

It is estimated that no more than 50 of these companies have their own installed capacity to undertake research and development activities. This activity has increased due to Law Number 20.241, issued on January 20, 2008, on tax incentives for private research activity. The main and most active are international companies with subsidiaries in Chile, such as BASF Chile, of the BASF international group, in the development of thermal insulation panels for construction; Knauf in the area of thermal coverings; Tecnopanel; Nova Chemical; Covintec; Grau home; and large-scale companies that produce cement and boards for construction such as Cementos Bío-Bío, Masisa and CMPC.

4.5. The typology of projects

The Science and Technology System in Chile handles the process of application of projects for competitive fund grants. For the purposes of research and development of products, processes or services, the following types of projects are subject to financing:

Basic research projects: experimental or theoretical studies, with high scientific content, carried out to obtain new knowledge about the fundamentals of the phenomena and observable facts, regardless of whether

they have a specific application or use. These projects are normally executed by higher education institutions.

Pre-competitive applied R&D projects: with greater or lesser scientific content, they are oriented towards generating economic and/or social impacts through the development of innovations in goods, services, processes, and marketing or organizational methods that, in addition, involve greater risk. They subsidize activities such as: research for the development of new goods or services; design and construction of prototypes or pilot plants; payment of royalties, patents and other third party rights, pre-investment studies, among others; actions that seek to reduce the inherent risks of the research field and to speed up arrival on the market. These projects are executed by research institutions associated with companies or other entities that give them relevance, or directly by companies with the support of research centers, depending on the stage of the research process carried out by the project. Research that is basic, applied and of public interest, can be resolved under the leadership of research centers and higher education institutions; development research is normally led by companies directly.

Applied R&D projects of public interest: With greater or lesser scientific content, these projects aim to develop public goods to reduce information asymmetries and problems of market failures. They generate products such as norms, standards and knowledge in general that serve to reduce uncertainty in critical decision-making for the success of the participants and final beneficiaries of the projects, thereby, improving the competitiveness and accelerating the undertaking. These projects are executed by research institutions associated with companies or other entities that give them relevance.

4.6. Cadastre of Housing Research Activity

4.6.1. Methodological approach

Descriptive analysis techniques are used to characterize, using quantitative criteria, the technological research carried out since the decade of the 1980s in Chile, when the system of competitive research grants started. The Oslo and Frascatti Manual is used to characterize the research and its results. It draws on primary and secondary sources such as: interviews, reviews of databases and research reports, and Web page inquiry; among others.

The proposed objective was to study the work undertaken in Chile from 1981, the year of the first national competition for research projects, under the research topic, development and transfer of technologies for energy and environmental improvement of housing in Chile; until 2012, when it was possible to obtain public information available in repositories of various institutions that manage the research field in Chile.

This gathering of information can be conceived as a baseline study to learn, among other things: how the needs of research and development have evolved, how they have been dealt with, and what their results have been. Have all the solutions been successful? Which solutions have been more successful and why? What can explain the unsuccessful cases? Are there technical or other reasons? This knowledge is regarded as fundamental to establish the deficit or failures in this matter and to define more precisely the strategies of innovation and technological development to improve the environmental and energy performance of the housing stock.

After defining the objective of the search, the work carried out focused on the following areas:

4.6.1.1. Review of databases:

Databases of the major public institutions responsible for the management of research activities for purposes of technological development in Chile include namely:

- The databases of the Fondecyt programs and CONICYT's Fondef
- The databases of the Innova programs and of Law Number 20.241 on CORFO's incentives for R&D

At Conicyt, the data collection procedure was conducted by year, directly from the institutional repository. In the case of Fondecyt projects, Chile's National Archives were also used, where reports of projects from 1981 until 2007 can be found, filed under the DFL Number 5.200, which officially regulates the entry of documents into that institution. From the respective reports, all of the information of interest is collected.

In the area of Corfo projects, the search was performed using key words, such as: housing, quality, energy efficiency, building systems, management and materials, in order to identify the projects' names. In the second stage, CORFO's internal repository, which consists of more than 6,000 titles and project reports of different natures, was reviewed (http://repositoriodigital.corfo.cl). In the third stage, reports available at CORFO's central library were reviewed and others were requested directly from the executants of the projects.

Regarding projects subject to the R&D Law, due to the confidential nature of the developments, an inquiry was made to the Transparency Unit of the Government of Chile (request for information Number AH004-W-0001966 on 20/03/2014), in accordance with Law Number 20285 on access to public

information. Information was specifically requested on construction sector projects and committed amounts of public and private investment.

4.6.1.2. Review of reports and interviews

The reports are provided by private individuals, companies and institutions. From them is requested information that is unavailable in public databases. Here, personal communications with institutional representatives of the major Research Centers in the field and/or researchers are considered. Private developments undertaken directly by companies and individuals that are not reflected in public databases are also considered.

4.6.1.3. Segregation by area and type of project

Oslo and Frascatti's Manual is used as a guide to technologically characterize the projects and their results. Distinctions are made based on:

Project type: pre-competitive (products of high individual adaptability that meet market needs and that are developed for commercial purposes); public interest (products with no individual adaptability that help to resolve information asymmetries and market failures).

Type of innovation: products, processes, services (related to technological innovations), marketing and organizational management (both considered non-technological innovations).

Quality of the result: New (meets existing needs in the market not covered by other products or services); Improved (substantially improves the characteristics of other products); adapted (adaptation without substantive improvements).

Level of development : Tested at an experimental level (the project ends with a prototype tested under controlled, unreal conditions); Tested at a pilot level (the project ends with a prototype tested under real conditions on a small scale); Tested at a pre-industrial level (the project ends with a prototype tested under real conditions at a productive or massive scale); Tested at a commercial level (the project ends with a prototype tested under real conditions on a productive or massive scale that has been put on the market).

Area of work: the projects, for purposes of analysis, are organized into the following seven thematic areas:

- **Materials and building components**: development of new and/or improved materials and building components, which stand out for their energy and environmental characteristics, life cycle, costs, among others.

- **Building systems**: development of new and/or improved systems for building dwellings, which stand out for their energy and environmental characteristics, life cycle, costs, among others.
- **Comfort and occupation:** studies of the variables of indoor climate and diagnostics of habitability conditions in housing.

- **Buildings physics:** studies of hygrothermal and acoustic properties; also, those related to the light of the building components (roofs, facades, windows, partitions, etc.), rooms, parts of buildings and buildings.

- **Quality management:** studies, developments and implementation of methods and tools for the energy and environmental improvement of housing.

- **Regulations and policies**: studies leading to the definition of standards, rules and regulations applicable to the energy and environmental improvement of housing.

- **Sustainable architecture and urban design:** studies and developments of passive design variables associated with architecture and land use planning for the energy and environmental improvement of housing.

- **Infrastructure:** projects that enable the creation of infrastructure for the development of research and technology transfer. Equipment and training of human resources to support the development of research activities and entrepreneurship.

Other descriptors: Year, Project Title, Executing Institution and Partners, Project Head, Costs.

Figure 4.2 shows the methodological scheme used to survey and characterize R&D activities performed in the area of technological development and innovation in residential buildings in Chile.

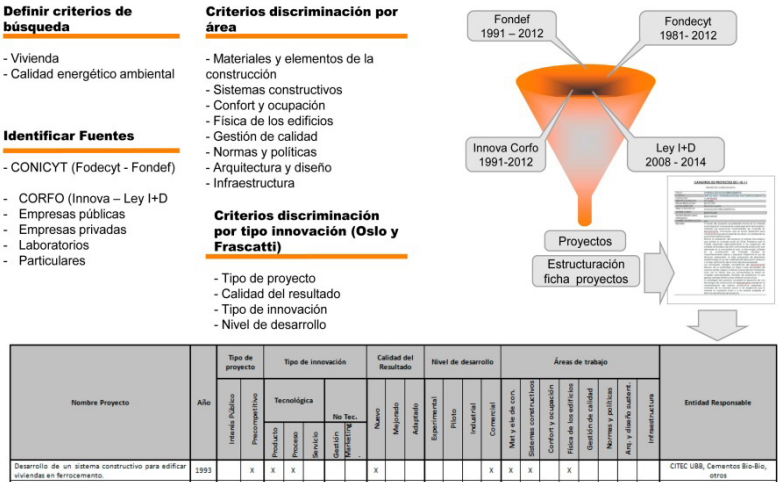


Figure 4.2: Methodological scheme used to survey and characterize R&D activities during the 1981-2012 period. Source: Created by the author.

4.6.2. Volume of activity and investment

Between 1981 and 2012, 8,470 Fondecyt projects were implemented. Out of this total, 14 projects are linked with the subject matter under study. The accumulated investment through Fondecyt reaches 1,479.4 million US dollars, of which 0.6 million UD dollars went to science research projects in the area of housing.

Between 1991 and 2012, 1,220 Fondef projects were executed, including 11 projects linked with the subject matter under study. The accumulated investment through Fondef for this period adds up to 286.8 million US dollars, of which 5.2 million US dollars went to applied research projects related to housing.

Between 1991 and 2012, a total of 7,132 Innova Corfo projects were executed, including 39 projects linked to the topic of housing. The investment made through Corfo for that period adds up to 3,349.2 million US dollars, of which 6 million US dollars went to mainly development research projects.

Between 2008 and 2014, a total of 136 initiatives were carried out under the R&D law for a total amount of 50 million US dollars. Of those initiatives, 15 correspond to the general area of construction and 4 of them to the specific area of residential building. The investment amounts in R&D reach 1.75 million US dollars.

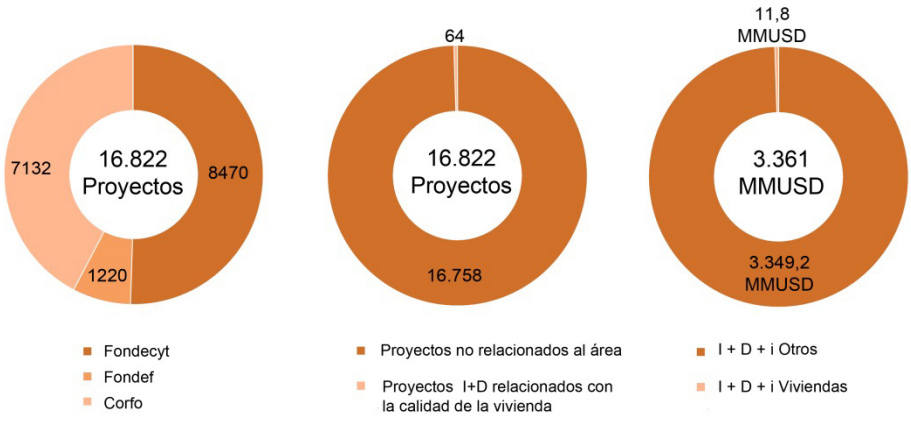


Figure 4.3: Projects and investment from Fondecyt, Fondef and Innova in the area of housing. Period 1981-2011. Source: Created by the author with data from Conicyt, Corfo and private individuals.

In summary: in the area of projects funded with competitive grants, a total of 64 projects can be identified from a universe of 16,822 projects related to the subject matter under study during the search period. In the area of projects certified under the R&D law, initiatives in the area do not exceed 4 out of a total of 136. All of this information is finally summarized in files for purposes of analysis and technological characterization.

4.6.3. Characteristics of housing research (1981-2012)

Tables 4.1, 4.2, 4.3 and 4.4 show a selection of projects considered to be most relevant of those financed through Fondecyt, Fondef, Innova Corfo and under the R+D law, respectively, with a start-up period of implementation between 1981 and 2012. The main descriptors are the areas of work (8), the project type (of public or business interest), the kind of innovation that results from its implementation (technological and non-technological), the innovative quality or merit of the project and its products (new, improved or adapted) and, the level of development of the products that are obtained at

the end of the project (tested at an experimental level up to a commercial level).

Figure 4.4 presents a series of facts on the type, nature and results of research carried out in Chile. In this regard:

Chile invests 0.4% of its GDP in research, a fifth of the average among OECD countries, of which the country is a member (OECD, 2013). The work and investment in research in all areas in Chile is very low and is particularly low in the area of residential construction. This survey shows only 64 R&D projects in the housing area between 1981 and 2012; this amount is equivalent to 0.38% of the research projects carried out in the country in all research areas which during this period add up to 16,822 projects. The resources invested in the housing area follow the same proportion.

What indicators or figures can be used to compare the commitment in the area of housing in Chile? The investment in construction for housing purposes during the period was 4.6% of the national GDP and 5.5% during the last decade (Rodriguez J et al., 2006); this figure attests to a clear imbalance between the importance given to research purposes and their contribution as a sector to the national economy.

Additionally, the implementation of the projects is concentrated in very few institutions and research groups. In all areas, no more than three institutions carry out more than 50% of the research and development work in the area of housing in Chile:

In the area of scientific Fondecyt projects: of the 14 projects awarded between 1981 and 2012 related to the topic, 10 projects (71%) were executed

individually or jointly by the Universities Bío-Bío (UBB) and Concepción (UdeC) and the Pontifical Catholic University of Chile (PUC).

In the area of Fondef applied research projects: of the 11 projects undertaken between 1991 and 2012 related to housing, 8 projects (72%) were executed individually or jointly by research groups from the UBB and PUC, in alliance with various companies and institutions in Chile and abroad, noteworthy among which are the Center for Architecture and Climate Research at the Catholic University of Louvain in Belgium, the Nobatek Center for Technological Innovation in France and the Eduardo Torroja Institute in Spain, among others.
In the area of Innova Corfo research and development projects: of the 39 projects carried out between 1991 and 2012 related to housing, 26 projects (67%) were executed by technology holdings formed by academic departments or R&D centers belonging to the UBB, the PUC and the Chilean Chamber of Construction's Technological Development Corporation (CDT), in addition to Chilean companies and various other institutions in Chile and abroad that exist as partners or constituents of the initiatives.

According to Conicyt and Corfo records, the group of researchers responsible for the work undertaken in Chile in the area (64 R&D projects during the observation period) does not exceed 40 researchers. The project directors and/or co-researchers, with relevant participation measured in terms of the number of appearances in the Corfo and Innova records, reduced to percentages, include: Ariel Bobadilla (34%); Gerardo Saelzer (16%); Ricardo Hempel (14%); Waldo Bustamante (14%); Leonardo Veas (11%); Adelqui Fissore (8%), Roberto Goycoolea (8%); Maureen Trebilcock (8%).[9]

[9] In recognition of the contribution of this author, as highlighted in this historical count, he was awarded the 2006 Municipal Prize in Applied Research with a

The participation of institutions and researchers is observed to be quite low in relative terms, considering the potential for carrying out research work. In the country, there are 59 universities, of which 16 belong to the state and 43 are privately owned. State universities and 9 of the private institutions receive contributions from the State and are obliged by law to undertake research. In addition, there are more than 400 research and transfer centers with some degree of accreditation, linked to various universities, public and private institutions and trade associations (MINEDUC, 2013). At least 11 centers identified in section 4.2 venture with greater or lesser success into the matter of housing for purposes of innovation and technological development in the sector.

In terms of the type of research projects that have been implemented in the country: There is a balance between public interest projects, aimed at resolving problems of information asymmetries and market failures, with those of productive interest oriented toward the development of various innovations for purposes of commercial exploitation. Regarding the type of innovation, product innovations prevail (48%), related to the development of materials and building components such as bricks, mortars, panels, etc., and processes (43%), mainly associated with new or improved building systems.

Mention in Construction Physics. This prize was given by Decree 1006 from the Illustrious Municipality of Conception, dated September 29, 2006, due to "his vast work in the innovation of materials and building systems and the configuration of quality systems based on performance of construction products such as windows and doors". This honored the 20-year career path of a research group from the UBB that I participated in as a collaborator in its beginnings in the late 80s and as director since 1995. The same group was officially established in 2008, by mandate of the State of Chile, through Innova Corfo project 06-FC-01-IXC-56, at The Center for Research in Construction Technologies at the University of the Bío-Bío, CITEC UBB.

With regard to the quality or innovative merit of the projects, there is a low innovative intensity; around 80% corresponds to research that results from adapting and improving existing technologies in the country or abroad. Few innovations are the result of the application of new knowledge developed from major R&D efforts involving changes close to the technological frontier. Due to their innovative merit, some of the Fondef projects in the area identified in Table 4.2 stand out, in particular the Fondef project Number D 01I1161 that gave rise to a series of new, heat resistant, ceramic bricks and thermal insulating cement mortars. These developments enabled the creation in Chile of the market for these products (Bobadilla and others, 2009). Some developments in building systems in Innova Corfo line have the same innovative character, which will be explained later.[10]

The level of development that projects reach at their end and/or post-project phase is another distinctive aspect of research in the area. The return on investment in development research is still esteemed to be relatively low: less than 2 in every 10 research projects result in products that are placed on the market (products, processes, services). Due to various circumstances, the majority does not pass the phases of technology tested at a pilot level, a phenomenon explained, among other reasons, by the lack of incentives for investments seeking to exploit products resulting from innovation projects. These investments always involve some degree of risk that the financial system and the State of Chile are not always willing to assume.

[10] The thermo-resistant ceramic brick technology (Patent Number 2738-2004), the thermo-resistant ceramic mass (Patent Number 1939-2005) and the Dry Mix insulating mortar stucco technology were developed in 2005 by a technological consortium formed by the Cementos Bío-Bío company, Princess Ceramics and CITEC UBB through the Fondef project D01I116, and whose director was this author.

Regarding the areas of work that show greater prominence, the development of materials and building systems (61%), the development of norms and standards (48%), quality management (32%) and construction physics (27%) stand out. This structure primarily responds to what the more basic or immediate or basic needs have been during the first three decades and, in particular, in the last decade in which more than 70% of the nation's research in the area was carried out. In relative terms, more emerging or minor developments are perceived in areas intended for studies of habitat and dwelling occupation, and those oriented towards the development of new and better options in design and architecture for housing in Chile.

Table 4.1: Most relevant Fondecyt Conicyt (Sciences) projects. Period 1981-2012

Nombre Proyecto	Año	Tipo de proyecto		Tipo de innovación					Calidad del Resultado			Nivel de desarrollo				Áreas de trabajo								Entidad Responsable
				Tecnológica			No Tecnológ.																	
		Interés Público	Precompetitiva	Producto	Proceso	Servicio	Gestión	marketing	Nuevo	Mejorado	Adaptado	Experimental	Piloto	Industrial	Comercial	Mat y ele de con.	Sistemas constructivos	Confort y ocupación	Física de los edificios	Gestión de calidad	Normas y políticas	Arq. y diseño sustent.	Infraestructura	
Inspección de la construcción de obras de edificación	1986	X		X	X						X	X								X	X			Depto. Ing. Civil PUC Chile, otros
Vivienda	1988	X		X	X						X	X								X	X			Depto. Ing. Civil PUC Chile, otros
Comportamiento térmico de viviendas	1989	X		X	X					X		X						X	X		X			CITECUBB, Depto. Ing. Mecánica UdeC, otros
La calidad residencial del entorno inmediato a la vivienda social	1989	X		X	X					X		X										X		Depto. Arq. PUC Chile, otros-
Soluciones constructivas para paramentos de cierre vertical en madera de calidad térmica apropiada para su uso en viviendas de interés social	1990		X	X	X				X				X			X	X		X					CITECUBB, Depto. Ing. Mecánica UdeC, otros
La ventilación en el diseño térmico de una vivienda	1992	X		X						X		X						X	X		X			CITECUBB, Depto. Ing. Mecánica UdeC, otros
Optimización e incorporación de sistemas pasivos a la arquitectura tradicional de la cuenca del Salar de Atacama	1992	X			X					X		X						X				X		Universidad Técnica Federico Santa María
Desarrollo de un programa de mejoramiento de la calidad para la construcción	1994	X			X					X		X								X	X			DICTUC, otros
Modelo de optimización térmica de viviendas	1996	X		X						X		X									X			Depto. Ing. Mecánica UdeC, otros
Modelo para el diseño óptimo de ventanas en la construcción	1999	X		X						X		X				X			X		X			Depto. Ing. Mecánica UdeC, otros
Enfriamiento ambiental de edificios de oficina a través de ventilación nocturna	2009	X			X					X		X									X	X		Depto. Arq. PUC Chile, otros -
Evaluation of different types of glazing and shading systems for improving energy performance and occupant's visual comfort of offices in central Chile	2011	X			X					X		X									X	X		Depto. Arq. PUC Chile, otros

Source: Created by the author with data from Conicyt

Table 4.2: Most relevant Fondef Conicyt (Applied Research) projects. Period 1991-2012

Nombre Proyecto	Año	Tipo de proyecto		Tipo de innovación					Calidad del Resultado			Nivel de desarrollo				Áreas de trabajo								Entidad Responsable
				Tecnológica			No Tecnológ.																	
		Interés Público	Precompetitiva	Producto	Proceso	Servicio	Gestión	marketing	Nuevo	Mejorado	Adaptado	Experimental	Piloto	Industrial	Comercial	Mat y ele de con.	Sistemas constructivos	Confort y ocupación	Física de los edificios	Gestión de calidad	Normas y políticas	Arq. y diseño sustent.	Infraestructura	
Mejoramiento de la gestión de producción en la construcción	2000		X				X			X			X								X				IDIEM U. de Chile, Empresa Constructora Bravo Izquierdo, otros
Determinación de los estándares de bienestar habitacional, para mejorar la calidad de la constr. de viviendas en Chile	2000	X		X						X			X						X						Fundación Chile, Colegio de Arquitectos de Chile A.G., otros
Desarrollo experimental de especificaciones técnicas para el mejoramiento higrotérmico de muros de albañilería de ladrillo y hormigón.	2001		X	X	X				X						X	X	X		X						CITEC UBB, DECON PUC, Climat UCL, otros
Diseño por envolvente para la vivienda de madera: innovación tecnológica para fomentar el uso del pino. radiata en Chile	2003		X	X	X					X			X			X	X								Depto. Arq. PUC, Corma, otros
Ahorro de energía y habitabilidad - Transferencia de un paquete Tecnológico para implementarlo en el sector habitacional	2004		X	X						X			X				X								DICTUC, Colegio de Arquitectos de Chile, Otros
La Buena Casa: Diseñopor envolvente para la vivienda de madera, FaseII: complejo techumbre y pisos	2006		X	X	X					X			X				X								Depto. Arq. PUC, Corma, otros
Diseño y aplicación de un sistema de aseguramiento de calidad para obras de construcción habitacional en Chile, basado en criterios y estándares de desempeño (performance)	2009		X	X					X						X						X	X			CITEC UBB, DECON PUC, Climat UCL, otros
Desarrollo e introducción del sistema de edificación pasiva en Chile	2009		X	X	X					X				X			X	X	X						CITEC UBB, Climat UCL
Desarrollo de bases técnicas y normativas para prototipos de vivienda modular, con énfasis en soluciones de emergencia, bajo criterios técnicos, geográficos y económicos que mejoren su eficiencia y funcionalidad.	2009	X		X						X			X								X	X			Depto. Arq. PUC, Corma, otros
Soluciones de muros de envolvente para casas de hormigón bajo criterios de desempeño energitérmico, estructural y constructivos	2010		X	X	X					X			X			X	X								Depto. Arq. PUC, Corma, otros
Establecimiento de clases de infiltración aceptable de edificios para Chile.	2010		X	X					X						X							X	X		CITEC UBB, DECON PUC, Climat UCL, otros

Source: Created by the author with data from Conicyt.

Table 4.3: Most relevant Innova Corfo (Development research) projects. Period 1991-2012

Nombre Proyecto	Año	Tipo de proyecto		Tipo de innovación					Calidad del Resultado			Nivel de desarrollo				Áreas de trabajo								Entidad Responsable
				Tecnológica			No Tecnológ.																	
		Interés Público	Precompetitiva	Producto	Proceso	Servicio	Gestión	marketing	Nuevo	Mejorado	Adaptado	Experimental	Piloto	Industrial	Comercial	Mat y ele de con.	Sistemas constructivos	Confort y ocupación	Física de los edificios	Gestión de calidad	Normas y políticas	Arq. y diseño sustent.	Infraestructura	
Desarrollo de un sistema constructivo para edificar viviendas en ferrocemento.	1993		X	X	X				X						X	X	X		X					CITECUBB, Cementos Bío Bío, otros
Viviendas industrializadas progresivas para el sector socio-económico bajo	1998		X		X						X				X		X			X				U.Católica Valparaíso, varias empresas
Desarrollo de un ensayo que permita validar el uso de bloques de hormigón en viviendas sociales	1999	X		X							X		X								X			Multicret S.A..
La madera en la vivienda social	1999		X		X		X				X		X			X				X				Instituto Forestal, Varias empresas
Vivienda social en ferrocemento	1999		X	X	X					X					X	X	X		X					CITECUBB, Cementos Bío Bío, otros
Desarrollo de recomendaciones especiales para el diseño de viviendas sociales de albañilería de 1 y 2 pisos	2000	X		X	X						X		X			X	X				X			Instituto Chileno del Cemento y Hormigón, varias empresas
Bases de certificación de calidad de la vivienda Dictuc.	2002		X	X			X			X					X					X	X			DICTUC, varias empresas
Diseño y elaboración de instrumentos para la especificación y adquisición de materiales de construcción	2002		X	X			X			X				X						X	X			Tulsa S. A. - Cesmec Ltda. -
Desarrollo de un sistema de apoyo a la planificación y gestión de producción en la construcción mediante un sistema computacional	2002		X	X			X			X			X							X	X			DICTUC, varias empresas
Desarrollo de una metodología para prevenir la ocurrencia de patologías en las viviendas sociales	2003	X		X	X					X			X						X	X				Instituto de la Construcción, DECON UC, CITECUBB, varias empresas
Sistema nacional de información para la gestión de calidad en proyectos de construcción	2003	X		X			X			X			X							X	X			Constructora Cuevas y Purcell
Centro Tecnológico para la calidad de la Vivienda	2005	X		X	X	X					X						X	X	X	X	X	X	X	CITECUBB, Climat UCL

Source: Created by the author with data from Corfo.

Table 4.4: Corfo R&D Law projects (Development) Period 2008-2014. Projects in the general area of construction certified by CORFO to March of 2014

Ítem	Contribuyente	Código	Monto en MM $	Fecha certificación	N° Resolución
1	Compañía Industrial El Volcán S.A.	SC-0010	14,61	27-11-2009	1362
2	Sociedad Punta de Lobos S.A.	SC-0012	57,66	24-12-2009	1567
3	Molibdenos y Metales S.A.	SC-0031	83,48	07-09-2010	1008
4	Constructora Pehuenche Ltda.	SC-0054	22,19	21-09-2011	855
5	Penetron Chile Limitada	SC-0060	14,6	12-08-2011	750
6	Compañía Industrial El Volcan S.A.	SC-0077	21,88	27-12-2011	1506
7	Compañía Minera Doña Inés de Collahuasi SCM	SC-0095	36	04-06-2012	616
8	Penetron Chile Limitada	PI-154	4,95	21-12-2012	1541
9	Cementos Bío-Bío S.A.	PI-154	55,11	21-12-2012	1541
10	Acciona Infraestructuras S.A. Agencia Chile	PI-217	30,8	01-03-2013	230
11	Acciona Concesiones Chile S.A.	PI-217	31,87	01-03-2013	230
12	Soluciones integrales de Reducción de Vibraciones S.A.	PI-305	30,35	12-06-2013	606
13	Soluciones integrales de Reducción de Vibraciones S.A.	PI-306	187,9	31-05-2013	575
14	Maestranza Diesel S.A.	PI-350	70,54	31-07-2013	823
15	SMC Pneumatics Chile S.A.	PI-407	89,52	30-08-2013	979
16	Soluciones integrales de Reducción de Vibraciones S.A.	PI-475	87,44	16-12-2013	1396
17	Indura S.A.	PI-504	37,42	29-11-2013	1303

Source: Created by the author with data from the Transparency Unit of the Chilean Government

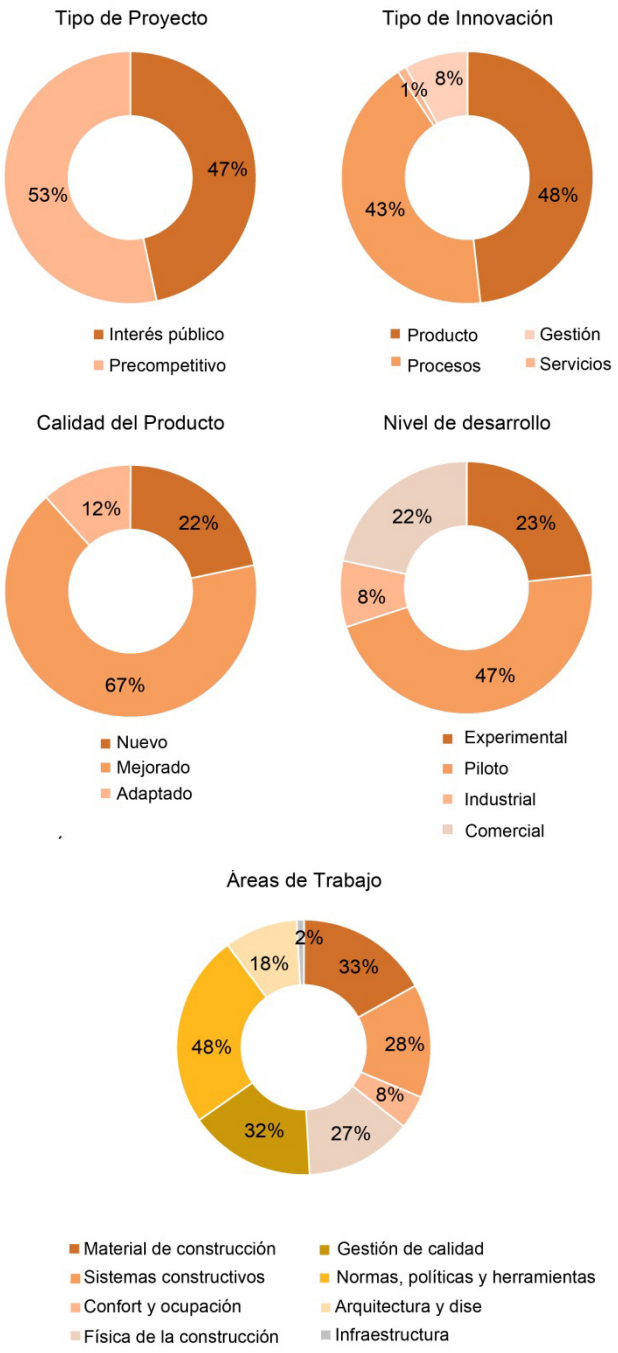


Figure 4.4. Technological characterization of the R&D work carried out in Chile between 1981 and 2012 through Conicyt and Corfo on the subject of Housing.
Source: Created by the author with data from Conicyt, Corfo and private individuals.

4.7. The New Building Systems

The Technical Directorate for the Study and Development of Housing (DITEC), part of the Ministry of Housing and Urban Development, is the unit that approves and monitors the use of non-traditional and industrialized construction systems for building dwellings in Chile, in accordance with Supreme Decree Number 27 (Housing and Urbanism) 1957.

The regulatory framework defines traditional building systems (SCT), non-traditional building systems (SCNT) and industrialized systems (S.I), as follows:

SCTs are those building systems whose construction and design are regulated by Chilean standards or foreign international standards recognized and used in Chile. SCNTs are those building systems whose structural conditions cannot be determined, totally or partially, by traditional calculation methods and/or, their on-site assembly is carried out with specially designed procedures, and/or they use new materials or these are combined in a way different than that described in the O.G.U.C. (Ordenanza General de Urbanismo y Construcción, the General Ordinance on Urbanism and Construction). Meanwhile, S.Is are those building systems whose main components, such as foundations, structures, walls, roofs and other equivalent elements or those of similar importance, are made or manufactured by repetitive procedures and mass-produced, following previously standardized designs and plans.

In practice, this means that the residential construction projects that use systems recognized as traditional are only backed up with calculation reports. Non-traditional systems must demonstrate testing certificates to prove minimum required performance levels in various areas: structural,

thermal, acoustic, and hydrological, among others. Figure 4.5 presents the framework that applies to both traditional and non-traditional systems.

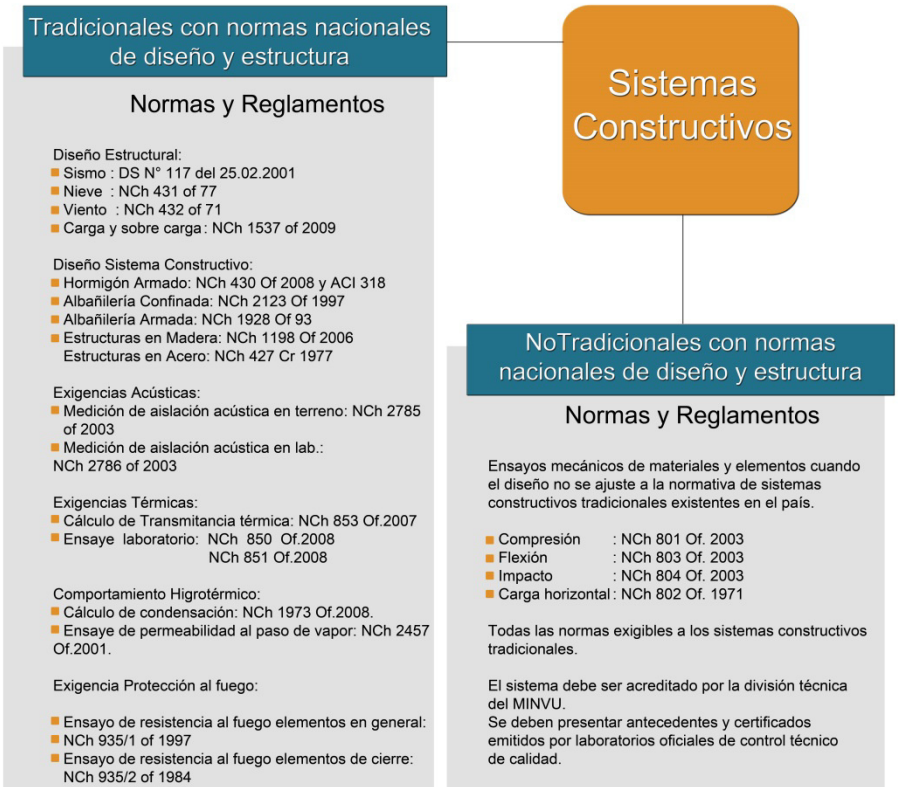


Figure 4.5: Regulatory framework that governs the design and use of building systems in Chile.
Source: created by the author with data from MINVU

Certification of materials characteristics and quality control are conducted by laboratories enrolled in the MINVU registers. The General Ordinance of Urbanism and Construction (O.G.U.C) in article 5.5.1 stipulates in this respect that: "The quality control of materials and industrial components for the construction sector shall be mandatory and shall be carried out by "Technical Control of Construction Quality" laboratories that are enrolled in MINVU's Official Register of Laboratories of Technical Control of Construction Quality, approved by Supreme Decree Number 10 (Housing

and Urbanism)". To date, there are 67 Technical Control of Construction Quality laboratories enrolled in the MINVU Register, of which only 3 laboratories have the necessary capabilities in the area of compliance evaluations related to hygrothermal protections and habitability in Chile (CITEC UBB; IDIEM and DICTUC), areas that are still clearly lacking in Chile.

Table 4.5 presents the non-traditional building systems authorized by MINVU to build dwellings in Chile to March of 2014. Currently, there are 21 accredited, non-traditional systems and 4 in the process of accreditation. The systems are mainly characterized by their speed of building, ease of transportation and assembly, and the use of new materials, such as products from work in technological innovation to varying degrees. Twelve of the technologies incorporated in Table 4.5 were certified in official CITEC UBB laboratories, 6 in IDIEM laboratories and 3 in DICTUC laboratories.

Most are foreign technologies that are used in Chile without modification; others are the result of processes of adaptation to local conditions, which introduce changes and modifications in different degrees to foreign technologies. The minority are the results of local development activities that derive from R&D projects.

Twelve of the 21 technologies correspond to systems of the Insulated Panel System (SIP) type, which was originally developed in the USA. This is a prefabricated version of the traditional timber frame system or post and beam construction. The panel consists of two parallel plates united with special adhesives to a central core of expanded polystyrene. The most common SIP system present in Chile was introduced by the Tecnopanel Company in 2008. It uses structural panel plates made of oriented strand board OSB, 9.5 mm thick in 1220 x 2440 x 75mm panels, and 11.1mm thick

in 1220 x 2440 x 90mm panels, as well as expanded polystyrene greater than 15 Kg/m³ in density and a state of the art adhesive with a polyurethane base. These panels can be used in structures as roofing, and walls and floors, using different configurations and joint and splicing systems. With these systems, thermal transmittances of building enclosures less than 0.5 W/m² K are obtained; a standard of protection far superior to that required by the Thermal Regulations in Chile.

All other SIP systems present on the national market are derived from the previous system, and essentially entail changes in the type of structural plate. The same company, Tecnopanel, introduced in 2011 a SIP made with cement fiber plates. In 2009, Termocret, introduced a SIP with wooden particleboard plates. In 2011, Termicasa introduced a SIP with thin metal plates. In 2012, Ram Chile introduced a SIP with magnesium oxide plates, etc. All these systems arise from the transfer of technologies and better practices available abroad to the local market, without any modification or technological adaptation, except for the verification of compliance of minimum required performances of any new system introduced into the local market in Chile.

Four of the 21 systems are the result of processes of adaptation to local conditions of foreign technologies that introduce changes and modifications resulting from minor R&D activities. Among these activities can be found systems based on panels consisting of three dimensional structures of welded wire with a core of polystyrene of different thickness and coatings based on cement mortars, which have been adapted to adjust their technical specifications to the structural and hygrothermal requirements in the nation. This is the case of the systems introduced by Covintec and Walltech in 2010 and Monoplac in 2011. Another four of the 21 systems are the result of R&D activities that incorporate higher levels of innovation and have given

rise to products which are classified as new products. These include the Ferrocement system introduced by the company Cementos Bío-Bío in 2002; Hormibal and Grau Home's systems introduced in 2011, which are variants of Ferrocement technology; and the HIT and VSP systems, made with 50 and 75mm thick panels of reinforced concrete and plates of expanded polystyrene of variable thickness depending on needs, which are bound by metal frames.[11]

The 21 technologies included in Table 4.5 represent 15% of the market at the moment; of those, Ferrocement technologies represent about 5% (INE, 2011). Virtually all of them have been incorporated into the national market in the past 10 years, as a response to the needs for greater productivity and quality and, mainly, due to the incorporation of new requirements in the construction ordinances in the last decade.

The incorporation of thermal, acoustic and fire resistance performance requirements obliged the industry to develop more competitive solutions to meet the new requirements and save the profit margins that the construction business requires. The new, mainly thermal requirements, forced many companies to make improvements to their building systems and, in minor cases simply change them. It is expected that this phenomenon will increase

[11] The Ferrocement system building dwellings was developed by the consortium formed by Citec UBB and the Cementos Bío-Bío Company through Fontec project Number 193-0273 in 1998 for homes up to one floor and Innova project Number 99CT3-V03 in 2002 for dwellings up to three floors. The same consortium with different associated companies developed in 2005 the HIT system (Innova Project Number 01-A1-022), the thermo-resistant concrete block technology used for the first time in Chile in the in the CITEC UBB corporate building (Innova Project Number 06-PCS1-004), and the solid nailed wood system (Innova Project Number 03-A1-184). This author participated as co investigator and/or director in all of these projects between the years 1995 and 2008. Nowadays, the same consortium is working on Innova Project Number 11IDI.1-10514, on the development of a "mortarless" concrete block technology without joining mortar for the Chilean market.

with the implementation of energy ratings and the new thermal standards that are currently under study.

Another two other circumstances also strongly influenced this process of technological renewal: the Ministry of Housing and Urban Development's 2009 call to re-certify building systems, which had the goal of verifying the compliance of building systems approved before 2007 to the new requirements; and the earthquake and subsequent tsunami on February 27, 2010, which meant the partial or total loss of more than 200,000 dwellings in Chile.

In order to respond rapidly to the demand for permanent homes, on the same lands of families affected by the earthquake so as not to affect their roots, the MINVU opted to support the creation of different typical projects, to be selected by the same families, considering the technical needs of each place. This generated a project bank of innovative technologies, with different degrees of industrialization, which in the end competed based on standard of quality, construction speed and cost. This process of technological opening-up encouraged many companies to develop and/or transfer and/or adapt construction technologies for use in the local market. Among these were several foreign companies in search of business opportunities in Chile.

Figures 4.6 and 4.7 show the technical specifications of two of the new systems most recognized in Chile: the Tecnopanel Company's SIP OSB system and the Cementos Bío-Bío Company's Ferrocement system. Appendix 1 presents the technical detail of other technologies for building dwellings on the national market.

Table 4.5: Non-traditional building systems accredited in Chile for the construction of subsidized housing financed by the State of Chile, to March of 2014 (21 new systems).

	Sistema	Año	Empresa	Característica
1	SIP OSB	2008	Tecnopanel	Panel estructural aislado en base a un alma de poliestireno expandido y tablero de OSB.
2	SIP Fibrocemento	2011	Tecnopanel	Panel estructural aislado en base a un alma de poliestireno expandido y placas de fibrocemento.
3	SIP Termocret OSB	2009	Termocret	Panel estructural aislado en base a un alma de lana de madera mineralizada y tablero de OSB.
4	SIP OSB Full Panel Avsa	2010	Full Panel	Panel estructural aislado en base a un alma de Poliestireno expandido y tablero de OSB.
5	Klasspanel SIP OSB	2010	Klasspanel	Panel estructural aislado en base a un alma de Poliestireno expandido y tablero de OSB.
6	LP SIP OSB	2011	LP	Panel estructural aislado en base a un alma de Poliestireno expandido y tablero de OSB.
7	VSP	2010	VSP	Sistema Acero Hormigón formado por un marco metálico y láminas de hormigón con poliestireno expandido.
8	ICF-Insulating Concrete Form	2010	Nova Chemical	Paneles de Poliestireno Expandido de alta densidad y hormigón armado, el cual provee un muro rígido.
9	ICF-Insulating Concrete Form	2010	Exacta	Paneles de Poliestireno Expandido de alta densidad y hormigón armado, el cual provee un muro rígido.
10	Sistema hormigón acero-núcleo	2010	Covintec	Estructura tridimensional de alambre electrosoldado con alma de Poliestireno expandido y estucado con mortero.
11	Hormigón acero-núcleo Poliestir.	2010	Walltech	Estructura tridimensional de alambre electrosoldado con alma de Poliestireno expandido y estucado con mortero.
12	Ferrocemento prefabricado	2011	Hormibal	Panel estructural prefabricado de hormigón armado. Se conforma como una estructura de albañilería.
13	Ferrocemento prefabricado	2010	Cementos Bio Bío	Sistema en base a placas de hormigón prefabricado con aislación térmica interior variable.
14	Hormigón acero-núcleo Poliestir.	2011	Monoplac	Panel estructural con alma de Poliestireno expandido. Las caras se conforman con una retícula de acero mortero
15	SIP placas de acero	2011	Arpa	Sin antecedentes
16	Ferrocemento prefabricado	2011	Grau Home	Paneles prefabricados con alma de Poliestireno expandido y caras en base a placas de hormigón armado.
17	SIP OSB	2011	9D	Panel estructural aislado en base a un alma de Poliestireno expandido y tablero de OSB.
18	SIP placas de acero	2011	Termicasa	Panel estructural aislado en base a un alma de poliestireno y chapas metálicas de bajo espesor.
19	SIP OSB	2012	Dryconing	Panel estructural aislado en base a un alma de poliestireno expandido y tablero de OSB.
20	SIP placa de óxido de	2012	Ram Chile	Panel estructural aislado en base a un alma de poliestireno expandido y tablero de placas de óxido
21	SIP OSB	2012	The Wall	Panel estructural aislado en base a un alma de Poliestireno expandido y tablero de OSB.

Source: created by the author with data from MINVU and private individuals.



Figure 4.6: Technical specifications of ferrocement technology for residential buildings in Chile developed by the Citec ubb - Cementos Bío-Bío consortium .

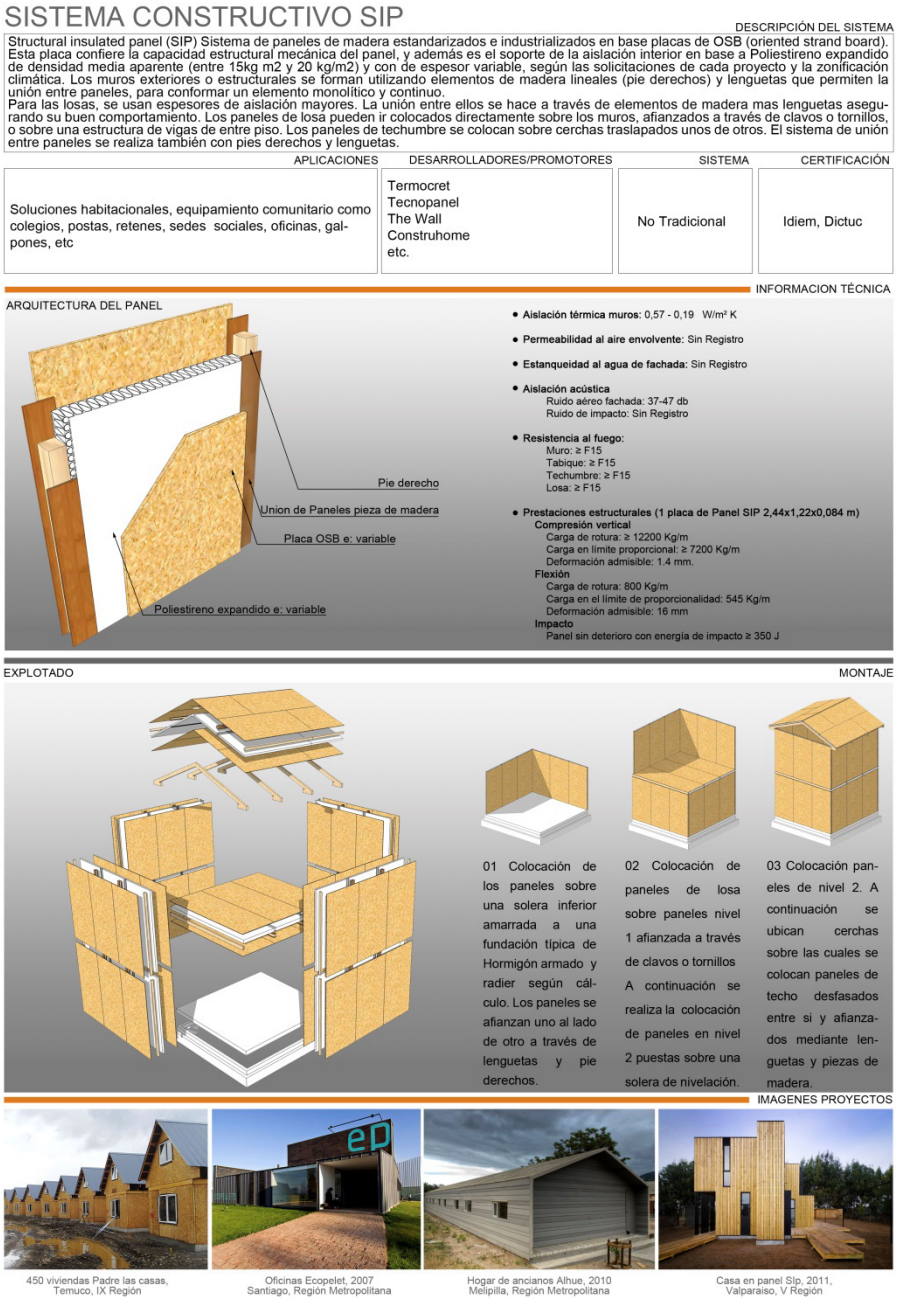


Figure 4.7: Technical specifications of the SIP Tecnopanel technology for residential buildings in Chile developed by Tecnopanel.

4.8. Chapter Conclusions and Comments

From the review of the research activity in the area of technological development of housing in Chile in the 1981-2012 periods, the following can be concluded:

The volume of research activity is very low and its effectiveness measured in terms of placement on the market is moderate. Considering the current state of development that research activity shows and the type and nature of the present and future demands of Chilean society, it is necessary to improve the volume and quality of work in and incorporate sustainability concepts and criteria across all areas. Development in the area should take on this challenge in the next 10 years in Chile.

The applied and development research in Chile needs the industry's backing to apply for grants for research projects. Thus, the needs for this type of research have evolved according to the needs and culture of innovation in the construction industry. In Chile, this is a powerful industry, little inclined to innovation. This situation explains the low volume of research work and the nature of the activities carried out. Most correspond to the transfer of technologies available abroad to the local market, without any change or technological adoption. In practice, there occurs an uncritical transfer of technology, especially of building systems and materials used with no degree of adoption to the seismic, climatic and cultural conditions in a country like Chile that extends for more than 4,000 km.

The low level of innovation in the residential construction industry is reflected in the reality of the market: 80% of the construction of dwellings still uses traditional building systems with concrete, and brick and block masonry, with very few modifications in the last 30 years. 15% uses non-

traditional systems incorporated into the residential construction market in the past 10 years. Most are prefabricated systems based on SIP panels (System Insulation Panel) which entered the country without any degree of technological adaptation to local conditions.

R&D needs have historically had the following origin: the thermal regulation, in its different stages in 2000, in 2007 and now in 2014, which has forced the industry to change in part its building systems and practices; the 2004 Construction Quality Law, which arose from strong social protests, obliged the entire construction collective to introduce changes to its quality assurance systems and a better understanding of the technical performance of the materials and housing as a whole; and the natural pressures to improve the productivity of projects and make the construction business more profitable.

The more prominent areas of work are: the development of materials and building systems (61%); development of norms and standards (48%); quality management (32%) and construction physics (27%). Incipient or minor developments can be seen in areas dedicated to studies of habitat and dwelling occupation and those oriented towards the development of new and better design and architecture options for housing in Chile.

72% of the research in Chile in the area, and the most important, was developed virtually during the last decade. The causes are those explained previously and, primarily, the increased supply and capacity for R&D in Chile. This enabled researchers educated at foreign universities to begin professional work, especially those trained at the Catholic University of Louvain, the University of Liege in Belgium and at the University of Nottingham in England, among others. Researchers educated in Louvain currently figure as responsible for over 50% of the research activity carried

out in the last three decades, as is evident from the number of entries in the Corfo and Innova records.

Although the ability to conduct research in Chile has grown considerably, there is not yet sufficient critical mass to meet all the challenges set out in the country related to energy and environmental improvement in residential construction, considering the current state of quality of the stock and society's quality requirements.

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5.0. REGULATIONS RELATED TO THE ENERGY QUALITY OF HOUSING IN CHILE

This chapter presents and discusses the progress in Chile to improve energy quality in the housing stock in terms of instruments and regulations. The legal framework in relation to planning, urbanization and the construction of housing is briefly explained, as well as the different mandatorily used instruments in this field, such as regulations, standards, and itemized technical building lists, among others, used from 1985 to 2013. This chapter discusses the types of regulations and standards, the degree or level of requirements, the accreditation mechanisms and, in particular, the work currently under way in these areas. The presentation is made retrospectively in order to observe the progress made over time, along with the difficulties and factors that have limited the creation and installation of a modern regulatory system for building in Chile.

5.1. Building and Energy Regulations

Nowadays, operating and maintaining buildings is an important part of the budget of families and nations. Thus, optimizing the relationship between the amount of energy consumed in buildings, the quality of the final services they provide, and the cost at which they are obtained is a challenge that has caused important changes in current building activity.

Reducing the amount of energy consumed in buildings and making buildings increasingly more sustainable are social demands that obligate periodic review of the activity of all actors involved in the construction of cities, particularly, the activity intended to establish the rules and regulations that govern the design and construction of buildings. Today, society demands

higher standards of energy efficiency in its buildings. This condition is increasingly valued by markets in order to achieve the recognition and acceptance that buildings need as products that are bought and sold (Meacham, B. J. et al, 2005; IRCC, 2010).

To this end, the political and legal systems of virtually all countries require buildings to have socially acceptable performances. This is normally accomplished by setting minimum requirements associated with safety, health, energy-saving and sustainability objectives, among others. Legislation generally incorporates these requirements in the form of rules, itemized technical building lists, regulations and ordinances. These legal instruments aim to guarantee that the building, once built and used in accordance with the regulations, provides acceptable performances for both the users and the community (Meacham, B. J. et al 2002). To this end, it is essential to carry out audits and regulatory inspections on the design, construction and operation of buildings in their various stages. These must be addressed by the building regulations and ordinances of each country, in the manner and at the level of complexity that enables their understanding, technological development and culture in relation to these matters.

5.2. General Law on Urban Planning and Constructions in Chile (L.G.U.C)

The Chilean Ministry of Housing and Urban Development (MINVU) is responsible for the country's housing policy and coordinating institutions that work with the government to run different plans and activities in the housing area (MINVU, 2014). The MINVU was established by Law Number 16,391, on December 16, 1965 Article 2 of this law defines the Ministry's 15 functions, the most important of which are:

1. To elaborate plans for urban and rural housing, community facilities and urban development.

2. To enact ordinances, regulations and general instructions on land development, housing construction, community facilities, planning and urban development, and housing cooperatives;

3. To monitor all aspects of urban planning, municipal and inter-municipal planning and their respective regulatory plans, housing developments, buildings and the implementation of relevant laws on the matter;

4. To participate in guiding and establishing a pricing policy for building materials and regulating and controlling their market;

5. To conduct and foment scientific research and professional and work-related development in terms of housing, urban development and construction productivity;

6. To promote the industrial production of housing and construction materials and the standardization of designs.

The MINVU is also responsible for studying modifications to the Law and its General Ordinance to keep it up-to-date with technological progress and socio-economic development. Subsequently, these changes must be approved by Supreme Decree. For the purposes indicated, "one can turn to the respective professional associations and seek advice from the technicians one deems convenient."

Consequently, it is the MINVU's task, in accordance with the law, to dictate the different types of ordinances and regulations that govern the planning,

design and construction of housing in Chile. The manner and mechanisms that must be used for these purposes are established in the General Law on Urban Planning and Constructions (L.G.U.C) DFL Number 458 (V. and U.) of 1975. This law defines three levels of action:

- The General Law on Urban Planning and Constructions (L.G.U.C), "contains the principles, powers, legal authority, responsibilities, rights, sanctions and remaining regulations that govern the organizations, employees, professionals and individuals, in the actions of urban planning, development and construction."

- The General Ordinance on Urban Planning and Constructions (O.G.U.C), "contains this law's regulations and regulates the administrative procedures, the urban planning process, development and construction, and the technical standards of design and construction required in the last two."

- The Technical Standards (N.T.), "contain and define the technical characteristics of the projects, materials and systems of construction and development, according to the compulsory requirements established by the General Ordinance." These mandatory standards are freely available to all those interested over the Internet.

In this way, the system that organizes building in the area of residential construction in Chile is defined by the General Law on Urban Planning and Constructions, its General Ordinance which makes it operational, and the technical standards that serve as auxiliary support. A large number of regulations are acknowledged as Official Standards; however, in this scheme the only mandatory standards are those incorporated into the General Ordinance on Constructions or another legally binding document on building regulation. Among the latter, is the Itemized Technical List for Construction

that the MINVU created in 2011 for its Solidarity Fund Housing Programs. Apart from the Ordinance, they are the only mandatory standards.

With regard to the regulations governing the quality of construction materials, the General Ordinance on Urban Planning and Constructions states, in Title 5, Article 5.5.1, that "the quality of the materials and industrial components for construction and the conditions for their use in works shall be subject to the prevailing official regulations and, in the absence of these, to the rules set by the techniques and art of construction." Regarding those responsible for oversight, it establishes that:

"The quality control of materials established in the previous paragraph shall be obligatory and shall be carried out by the Technical Control Laboratories for Construction Quality that are enrolled in the Ministry of Housing and Urban Development's Official Register of Technical Control Laboratories for Construction Quality according to decree Number 10 of the Ministry of Housing and Urban Development, on January 1, 2001." Moreover, it specifies that the regulation should be implemented in a manner that "encourages the use of industrial materials and components with the best technical and economic characteristics." As regards the regulations that govern design, the General Law on Urban Planning and Constructions, in Title III, Chapter I, Article 105, stipulates that: "The design of development and construction projects must comply with the standards set by the General Ordinance with regard to:

a) Urban road networks;
b) Green spaces and equipment;
c) Building lines, gradients, heights, overhangs, balconies, etc.;
d) Minimum dimensions of spaces, according to their specific use (room, business, office, school, health care, circulation, etc.);

e) Stability and earthquake-resistance conditions;
f) Fire-resistance conditions;
g) Sanitation, lighting, and ventilation conditions and;
h) Provision of health and energy services, and other matters set by the General Ordinance."

Article 106 of the L.G.U.C establishes that "to achieve the intended objective in the preceding article, the materials and systems used in housing developments and buildings must comply with the "technical standards" prepared by the Ministry of Housing and Urban Development, their dependent services or the National Institute of Standardization.

As of January 2014, there are 187 mandatory regulations in the area of construction and urban planning, which are declared in various documents that have the force of law; 68 are in the General Ordinance on Constructions. The number of regulations per area are: Environmental Conditioning, 37; Concrete, 44; Asphalt and asphalt mixes, 20; Elements and Components, 34; Wood, 17; Metal, 25; Soil mechanics, 9, Plastic, 1 (MINVU, 2014).

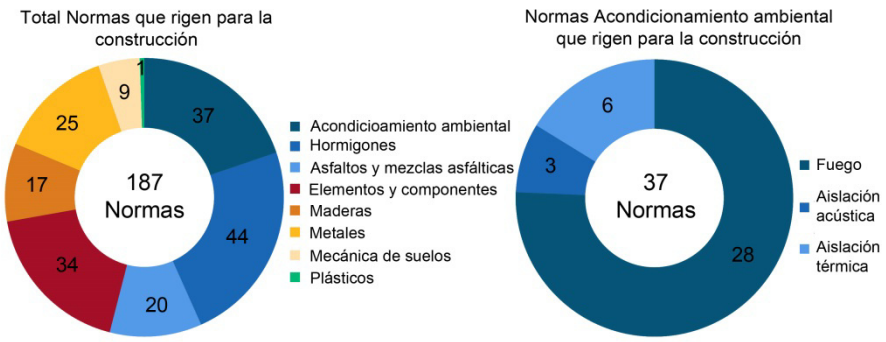


Figure 5.1: Mandatory regulations for housing construction in Chile.
Source: Created by the author with data from the MINVU

Within the area of Environmental Conditioning: 28 regulations cover aspects of fire prevention; 3 regulations aspects of resistance to sound and only 6 regulations relate to the thermal insulation and energy performance of buildings. Four of them are incorporated directly in the constructions ordinance and are applicable for all housing built in Chile and two incorporated in 2012 only apply to social housing in the Solidarity Fund for Housing program. In this regard, Chile is clearly deficient.

5.3. Evolution and State of Energy Regulations in Housing

The regulations related to energy matters in residential construction are recorded in the following regulatory documents of the building sector in Chile:

- The General Ordinance on Urban Planning and Constructions, Article 4.1.10, which includes the Thermal Regulations for Housing that apply to all types of dwellings;
- In the official technical standards on the matter that are incorporated into the Ordinance; and
- In the national and regional itemized technical lists for dwellings with state funding.

The manner in which these issues have developed over time in Chile is shown in Figure 5.2.

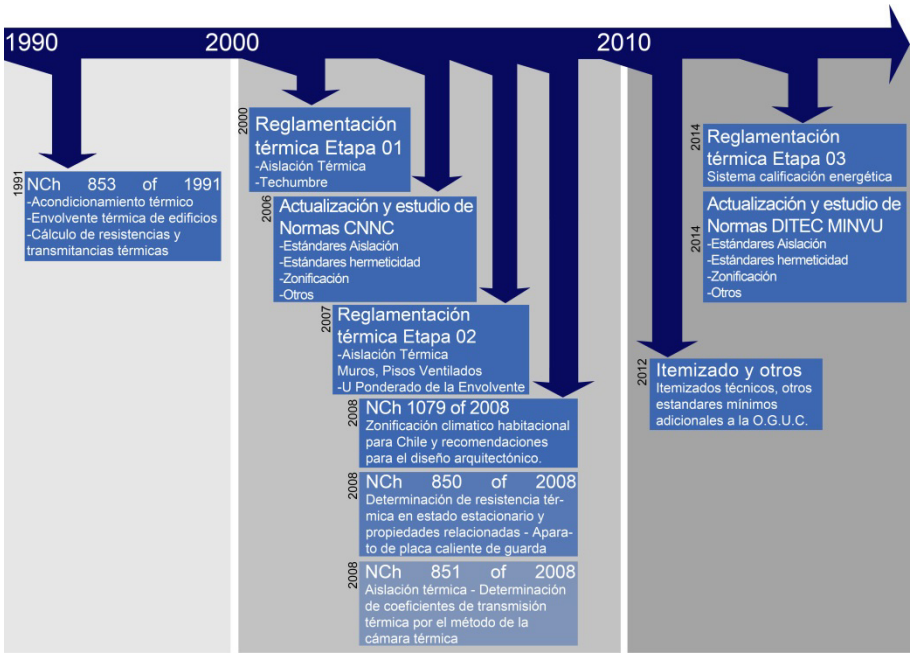


Figure 5.2: Emergence in time of regulations related to the energy performance of housing in Chile. Source: Created by the author.

5.3.1. Technical standards related to the energy performance of housing

The General Ordinance on Urban Planning and Constructions, as of January 2014, includes only four technical standards related to the energy performance of housing: NCh 853 on the calculation of thermal insulation, appended in 1991; NCh 850 and NCh 851 on thermal insulation tests, appended in 1991; and NCh 1079 on thermal insulation requirements and territorial zoning for architectural purposes, newly appended in 2008. In this regard:

5.3.1.1. Official standard for thermal calculation of envelopes

This is standard NCh 853: "Heating and cooling - Thermal envelope of buildings - Calculation of thermal resistance and transmittance." This standard pertains to the Area of Environmental Conditioning and was developed by the Standards Division of the National Standardization Institute. Representative members of universities, the industry and the Ministry of Housing participated in the study of this regulation. This was the first mandatory technical standard associated with the energy performance of housing in Chile; it was incorporated into the OGUC in 1991. It defines the calculation procedures to determine the thermal resistance and transmittance of building components, in particular those in the thermal envelope.

It was created with the main purpose of supporting the Thermal Regulations for Housing which at that time were being considered for implementation. Based on Fourier's Law of steady-state conduction, it incorporates relatively simple calculation methods that are useful for the calculation of heat transfer, heating power, cooling, thermal energy and the thermal insulation of building envelopes, when the thermal conductivity properties of the materials are known. It incorporated a list of the thermal conductivity properties of materials, some obtained by tests at the Institute for Research and Testing of Materials, IDIEM, at the University of Chile. To that date, this was the only laboratory in Chile with the ability to measure these properties.

In 2007, NCh 853 was updated based on the same standard, which only introduced minor changes, mainly clarifications regarding case studies. At that time, the adoption of an international calculation standard was evaluated, specifically ISO 6946:1996, which was more oriented to the

improvement of the thermal performance of buildings and their sustainability. This was not possible due to lack of complementary policy support and sufficient competent personnel to enable its correct implementation. In this way, the development of such support was put on hold.

Finally at the end of 2013, a new calculation standard was put out to public consultation, which replaced the existing 2007 regulations. This new standard, which is expected to take effect in late 2014, is identical to the English version of the International Standard ISO 6946:2007 "Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation method." This standard's form and content are different than the previous regulations. Its adoption aims to deliver better "means of evaluating the contribution of the products and service facilities of construction, to the energy conservation and overall energy efficiency of buildings."

The new standard incorporates more elaborate and supposedly more precise calculation methods, to address elements with air chambers, elements with sections of variable thickness, elements that contain heterogeneous layers including the effect of metal fasteners, elements with openings different than those of glazed elements, and calculations of surface resistance that differentiate based on emissivity and wind speed, among others. In addition, it incorporates procedures to correct, when relevant, the effects of gaps in insulation, the effects of mechanical fasteners that penetrate a layer of insulation, and the effects of precipitation in inverted roofs. It also includes methods for estimating the maximum expected relative error, when it is required that calculated thermal transmittance meets specific accuracy criteria.

The process of incorporating this new standard obliged the adoption of three other complementary standards: Standard NCh 849:2007, on physical quantities and definitions (translation of ISO 7345); Standard NCh 3077:2007, on procedures for accrediting the thermal properties of materials and elements (translation of ISO 10456) and Standard NCh 3078:2008 (translation of ISO 13789) on calculation methods in special cases of transmission and ventilation heat transfer coefficients.

The new regulation makes an important effort "to better assess the contribution of the construction elements in the building envelope to energy conservation and the overall energy efficiency of buildings." Evaluations carried out at CITEC UBB in late 2013 show that the standard enables a better understanding of transport phenomena and greater calculation accuracy; however, the increased complexity of the regulation does not necessarily aid in an improved estimation of the thermal performance of the elements. The thermal properties of many materials are still unknown and default values are assumed, which are not always correct; neither are corrections for moisture considered.

All these factors affect the quality of the estimates when making design decisions. Progress must also be made on these fronts. It does not seem justifiable to use a standard that requires more time and resources if improvements in the estimation of the thermal performance of the elements or of the building are not achieved.

5.3.1.2. Official testing standard for the determination of thermal resistance of steady-state materials.

NCh 850 serves for these purposes: "Determination of steady-state thermal resistance and related properties - Guarded Hot Plat Apparatus". This standard pertains to the Area of Environmental Conditioning and was developed by the Standards Division of the National Standardization Institute. Representative members of universities, the industry and the Ministry of Housing participated in the study of this regulation. The standard establishes a procedure to determine steady-state thermal conductivity by the guard ring method. It applies to homogeneous materials with flat and parallel surfaces, especially those used in the construction field such as thermal insulators and sheets, whose density and moisture characteristics and average temperatures are known. This is the first standard for testing materials in the area. Declared as an Official Standard of the Republic [of Chile] by the decree DS MINVU Number 58, in April 1983, it was based on the standard ACTM C177: "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus."

In 2008, the testing standard was changed to the International Standard ISO 8302: 1991 Thermal insulation – Determination of steady-state thermal resistance and related properties – Guarded hot plate apparatus," which translated into Spanish is currently in effect.

The new standard uses the same testing method, but introduces a series of changes to the previous regulation, designed to improve the accuracy and reliability of the results. At the time, it required laboratories to modify their testing procedures and incorporate more accurate measurement equipment and standardized methods of error and tolerance calculation for the

determination of temperatures, flows, and reported final conductivity. It also included greater technical details on the characteristics of samples, equipment used, testing conditions and systems of patterns for key variables of the measurement process. The changes were justified, in this case, by a series of discrepancies in the results that some laboratories were delivering; at the time three were located in Chile.

The process of adoption of the new standard was long and not without difficulties. Errors in measurement and the interpretation of data, and certificates that attributed properties the materials did not have and were impossible to achieve, resulted in the suspension of one laboratory. To date, only two laboratories in Chile maintain their status as official thermal conductivity testing laboratories.

5.3.1.3. Official testing standard for the determination of thermal transmission coefficients of elements

This is standard NCh851: "Determination of thermal transmission coefficients with the hot box method." This standard pertains to the Area of Environmental Conditioning and was developed by the Standards Division of the National Standardization Institute. Representative members of universities, the industry and the Ministry of Housing participated in the study of this regulation. The standard establishes a procedure for experimentally determining the thermal transmission coefficients of construction elements with the hot box method. The method is useful for measuring samples of flat and parallel faces of non-homogeneous construction elements such as walls, partitions, doors, glazed elements and other similar items. It was declared as an Official Standard of the Republic [of Chile] with decree DS Number 58, in April 1983, by the Ministry of Housing and Urban Development and is entirely based on the standard

ASTM C236: "Standard Test Method for Steady-State Thermal Performance of Building Assemblies by means of a Guarded Hot Box."

In 2008, the testing standard was changed to the International Standard ISO 8990:1994: Thermal insulation -- Determination of steady-state thermal transmission properties -- Calibrated and guarded hot box. This standard was duly translated into Spanish and adopted as the Chilean regulation. The new standard introduces a series of changes aimed at improving the accuracy and reliability of the determinations. It is heavily focused on the principles for the design of the hot box and the minimum requirements for the determination, in the laboratory, of the thermal transmission properties of construction elements. It places special emphasis on certain minimum conditions for the design of the apparatus, the procedures for sample preparation and tests, the methods of calibration and determination of errors, etc.

The new standard requires a minimum measurement area of one square meter, which required a change in the design of the measuring devices at the three laboratories that used the technique. All of this led to a process of equipment modification and learning that took over three years in Chile. The experience gained by CITEC in this regard is that the changes help to maintain better registers and monitoring of the testing process in all its phases, reduce the risks of measurement errors, and improve the approval of the laboratory service. It also enables better development of the ISO 17025 quality assurance system, which the laboratory must maintain to retain its status as an official laboratory in the country. However, no differences are detected in the value of the property obtained using one or another of the standards.

5.3.1.4. Standards for climatic housing zoning

NCh 1079 is of use for these purposes: "Climatic housing zoning for Chile and recommendations for architectural design." This standard pertains to the Area of Environmental Conditioning and was developed by the Standards Division of the National Standardization Institute. Representative members of universities, the industry and the Ministry of Housing participated in the study of this regulation. The standard establishes climatic housing zoning for Chile, in order to facilitate appropriate architectural design. It incorporates, in appendices that are not part of the regulation, recommended thermal insulation standards for elements of the envelope in the different zones, and weather data from the main cities in Chile.

The application of NCh 1079 has been obligatory in dwellings since 2009, through Supreme Decree (E) (MINVU) Number 778, December 9, 2009. An official standard in Chile since 1977, it is considered the first standard on the relationship between climate and architecture in Chile and is based on a investigation carried out by Rodríguez (Rodríguez, G. 1972) during the 1970s. It was promulgated by Supreme Decree Number 1474 of the Ministry of Public Works on November 17, 1977, for use in public buildings. The standard, valid for use in homes, is entirely based on the official 1977 standard, plus extra information provided by the Meteorological Service of Chile and by members of the committee responsible for its drafting.

NCh 1079 divides the country into nine zones for architectural design purposes, as explained in Chapter 2, section 2.1.2. This standard set out the first proposal of thermal insulation requirements for elements of the housing envelope in Chile only a few years after the energy crisis of the '70s. However, these requirements, which are contained in an appendix of the standard, are not mandatory. Only the requirements in the thermal regulation

that came into force in 2007 are mandatory. These are clearly inferior to the requirements recommended in the '70s by NCh 1079.

The criteria for thermal insulation in NCh 1079 are more demanding than those in the Thermal Regulation, except in some cases related to roofing. Clearly, the limit values of thermal transmittance for walls established by the regulation in several zones are not compatible with the needs of optimum minimum use of energy. In Concepción, for example, the regulation sets the transmittance limit for walls at 1.7 W/m² K and NCh 1079 sets it at 0.6 W/m² K. The low insulating capacity of the walls in the city of Concepción, and in all localities in the country's south-central zone, explain the housing stock's poor energy performance and many of the post-sale defect problems due to condensation (CITEC UBB, 2013a and 2013b).

Standard NCh 1079 was conceived in the decade of the 70s with energy efficiency and sustainability criteria; thus, it is considered to be ahead of its time. Its recommendations remain fully in force today; nonetheless, its recommendations for thermal protection have never become mandatory. This situation is explained by two phenomena strongly rooted in Chilean society: the strong opposition of the industrial sector to initiatives in this regard; and resistance from the state to investing more in the quality of housing. These problems have yet to be overcome and are discussed later.

The NCh 1079 standard was updated in 2008 and incorporated, among other modifications, climate databases of typical months in 48 localities in the country, with a return period of 30 years. The source is the Meteorological Service of Chile and is understood to be official reference information. The standard has acquired great importance in recent years due to its orientation toward energy saving and efficiency, criteria that are currently gaining greater importance in the country.

The Architecture Directorate at the Ministry of Public Works already introduced these criteria in some contracts for the design and construction of public buildings in Chile, through the creation of Standardized Reference Terms TDRe[12] (DA MOP, CITEC UBB, and DECON UC, 2012).

5.3.1.5. Standards under study

The policy framework in Chile is clearly deficient. A report by the Construction Institute in 2002 identified 2,583 technical standards for general use in force in Chile; this number can be compared with the 27,179 standards in Germany, 7,710 standards in Argentina and 17,170 standards in Belgium (IC, 2005). The official construction sector regulations number around 400, of which no more than 150 are mandatory (INE, 2014).

The OGUC currently includes 187 standards related to urban planning and buildings. The quantity of standards seems insufficient. Furthermore, many are old, so their rules do not properly aid in the development of the activity in the terms that society demands. New standards must be implemented and others must be updated, which is a process that presents a serious difficulty in Chile at present.

Since 1995, the standards that the National Standardization Institute (INN) produces are exclusively those requested and funded by the private sector. Hence, since that date, the processes of standards creation and/or upgrading

[12] The Standardized Reference Terms (TDRe), with energy efficiency and environmental comfort parameters for public buildings, are technical guides that the Architecture Directorate at the Ministry of Public Works began to incorporate in 2013 in Invitations to Tender for the Design and Construction of Public Buildings. These documents define by zone and building type the requirements, indicators, performance criteria (limit values) and procedures for requirement verification in the design and construction phases before handover. It includes requirements and methods of verification of energy demand for thermal conditioning and lighting, air quality, and acoustic insulation, among others. They were developed by a consortium led by the author of this thesis, made up of the Center for Research in Construction Technologies at the University of the Bío-Bío (CITEC UBB) and the School of Civil Construction's Directorate of Outreach in Construction at the Pontifical Catholic University of Chile (DECON UC).

respond almost exclusively to the interests of one company or another. In this scenario, standards of general public interest receive little to no favorable reception, in particular those aimed at setting requirements of any nature.

With the purpose of avoiding this structural difficulty and to respond to the need to improve the regulatory system, at least two major initiatives have been developed in Chile. The first is the creation of the National Council for the Standardization of Construction (CNNC) in 2002, led by the Construction Institute. This Council arose as a response to the need to articulate the sectorial demand for standards, so as to reconcile the national reality with international criteria. The second is Innova Project 06CN12ICM-32: "Update and study of Chilean standards to improve quality in the construction sector," at the behest of the National Standardization Council, the Ministry of Housing and construction trade associations.

The Innova project examined the development and/or updating of 66 regulations, particularly, those in areas where private initiative does not have a specific interest. In addition, technical groups at the Ministry of Housing are evaluating the incorporation of 6 other regulations into the OGUC. Together, both initiatives include a total of 24 standards related to the habitat and energy efficiency of buildings: 15 of them are related to the hygrothermal behavior of materials and constructions; 4 are about the air permeability of materials and buildings; 3 are on the air quality, ventilation and airtightness of buildings[13]; and 2 are about the water permeability of facades.

[13] In March 2014, MINVU put NTM 011/3 2014 out for public consultation: Requirements and accreditation mechanisms for the environmental conditioning of buildings. This regulation, which is an exception to the manner in which these matters are dealt with in Chile, includes acceptable airtightness classes for buildings in Chile. Such requirements were taken from the proposal of classes of building

Table 5.1 presents the regulations mentioned above. They primarily relate to requirement and testing regulations. With a few exceptions, the strategy followed, which is not always recommendable, includes the cancellation of a current standard and/or the adoption of an international standard, preferably ISO, which is translated and labeled as a national standard, with merely editorial changes. This does not present problems in testing or basic definitional regulations, but it does pose problems in those that involve requirements, where uncritical adoption can lead to serious conflicts.

Such a case has arisen with the application of regulation NCh 1973, on the hygrothermal behavior of building elements and components (translated version from ISO 13788:2012). The regulation defines the calculation of risk of indoor climate condensation conditions, specifically of relative humidity, that are not related with the external environment or with the culture of occupation of dwellings in Chile.

Use of the regulation generates design errors, to which are attributed many of the pathologies associated with condensation in the south central area of the country[14].

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airtightness that was proposed by Fondef Project D10 I 1025 and developed by a technological consortium formed by CITEC UBB, DECON UC and national and foreign institutions and companies. The classes proposed are a wager, properly adjusted to the country's climatic needs and the current state of airtightness in Chile's housing stock. Along with these classes, the project developed envelope design solutions to meet airtightness requirements throughout the nation.

[14] In December of 2013, the MINVU put out for public tender (ID 587-78-LE13) the study: Hygrothermal behavior of materials and building solutions commonly used in the envelope of social housing. It was awarded to CITEC UBB. Its main objective is to adapt the regulation by integrating use and weather variables throughout the country, considering that the load and type of indoor humidity the regulation uses and takes as reference to define the performance criteria of the envelope elements are deduced from Western European buildings, as the regulation expressly indicates. The project also includes the development of envelopes to support the architectural design of the main construction systems used in the country and the creation of a public database on the vapor permeability properties of materials, accredited by

Most of the regulations are under study and in the process of public consultation, which is the last stage prior to their incorporation into the OGUC. Four of these regulations were already incorporated into the Itemized Technical list for Constructions in 2012, as explained in 5.3.1. It is expected that by the end of 2014, at least 4 of them will be incorporated into the OGUC.

The full implementation of this package of 24 regulations, represents a tremendous challenge for Chile. The promulgation of regulations on such complex matters requires the existence of the necessary support for their application. This includes technical and professional teams prepared to work with design, monitoring and quality control; the existence of sufficient laboratory infrastructure; and greater economic resources to finance the increase in costs that the commissioning of new regulations brings at all levels. All of these conditions are not currently present in Chile and represent critical success factors for the full implementation of a modern regulatory system for building in the country.

There is an awareness of the lack of complimentary support. The promoters and facilitators of this process of regulation renewal, led in Chile by the Technological Division of the Ministry of Housing, expect that the institutions dedicated to training, research and technical assistance, and especially the field's laboratories, develop the capabilities required to adequately meet the needs imposed by the battery of standards that are expected to be implemented in Chile.

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testing certificates. A need in Chile; the permeability properties of the majority of the materials used in housing construction are unknown.

Table 5.1: Standards under study and in process of incorporation into the General Ordinance on Urban Planning and Constructions as of March 2014.

Ítem	Norma chilena	Correspondencia
	HIGROTERMICA	
1	**NCh1973: 2008:** Comportamiento higrotérmico de elementos y componentes de construcción - Temperatura superficial interior para evitar la humedad superficial crítica y la condensación intersticial - Métodos de cálculo	ISO13788:2012
2	**NCh2457: 2001:** Materiales de construcción y aislación - Determinación de la permeabilidad al vapor de agua (humedad)	UNE - EN 12086:1997 / ISO 12572:2001
3	**NCh 853: 2007:** Acondicionamiento térmico - Envolvente térmica de edificios - Cálculo de resistencias y transmitancias térmicas	ISO6946:2007
4	**NCh 2791: 2003:** Desempeño higrotérmico de los materiales y productos para la construcción - Determinación de las propiedades de absorción higroscópica	ISO6946:2007
5	**NCh3136/1: 2008:** Puentes térmicos en construcción de edificios - Flujos de calor y temperaturas de superficie - Parte 1: Métodos generales de cálculo	ISO 10211:2007
6	**NCh3137/1: 2008:** Comportamiento térmico de ventanas, puertas y contraventanas - Cálculo de transmitancia térmica - Parte 1: Generalidades *	ISO 10077-1:2006
7	**NCh3137/2: 2008:** Comportamiento térmico de ventanas, puertas y contraventanas - Cálculo de transmitancia térmica - Parte 2: Método numérico para marcos *	ISO 10077-2:2003
8	**NCh3076/1: 2008:** Comportamiento térmico de puertas y ventanas - Determinación de la transmitancia térmica por el método de la cámara térmica - Parte 1: Puertas y Ventanas *	ISO 12567-1:2002
9	**NCh3076/2: 2008:** Comportamiento térmico de puertas y ventanas - Determinación de la transmitancia térmica por el método de la cámara térmica - Parte 2: Ventanas de Techumbre y otras ventanas salientes *	ISO12567-2:2005
10	**NCh3117: 2008:** Comportamiento térmico de edificios - Transmisión de calor por el terreno - Métodos de cálculo *	-
11	**NCh2251: 2010:** Aislación térmica - Requisitos de rotulación de materiales aislantes *	-
12	**NCh 849:2007:** Aislamiento térmico-Magnitudes físicas y definiciones	ISO 7345
13	**NCh 3078:2008:** Prestaciones térmicas de los edificios - Coeficientes de transferencia de calor por transmisión y ventilación - Método de cálculo.	ISO 13789
14	**NCh 3077: 2007**: Materiales y productos de construcción. Determinación de los valores térmicos declarados y de diseño	ISO 10456:2001
15	**NTM 011/2 2014**: Requisitos y mecanismos de acreditación para acondicionamiento ambiental de las edificaciones. Parte 2: Comportamiento higrotérmico	-
	PERMEABILIDAD AL AIRE	
16	**NCh 3294: 2013:** Materiales de Construcción - Determinación de la permeabilidad al aire de los materiales - Métodos de ensayo	ASTM E2178-13
17	**NCh 3295: 2013:** Determinación de la permeabilidad al aire en edificios - método de presurización por medio de ventilador	ASTM E779-10
18	**NCh 3296:** Puertas y Ventanas - Permeabilidad al aire - Clasificación	UNEEN12207:2000
19	**NCh 3297:** Puertas y Ventanas - Permeabilidad al aire - Ensayos	UNEEN1026:2000
	VENTILACION Y CALIDAD DEL AIRE	
20	**NCh 3308:** Ventilación - Calidad aceptable de aire interior - Requisitos	ANSI/ASHRAE 62.1.2010
21	**NCh 3309:** Ventilación - Calidad de aire interior aceptable en edificios residenciales de baja altura - Requisitos	ANSI/ASHRAE 62.2.2013
22	**NTM 011/3 2014:** Requisitos y mecanismos de acreditación para acondicionamiento ambiental de las edificaciones. Parte 3: Calidad del aire interior.	-
	PERMEABILIDAD AL AGUA	
23	**NCh 3303**: Standard Test Method for Field Determination of Water Penetration of Mansonry Wall Surfaces	ASTM c1601-11
24	**UNE-EN 1928:** Laminas flexibles para impermeabilización - Láminas bituminosas, plásticas y de caucho para la impermeabilización de cubiertas - Determinación de estanquidad al agua	UNE-EN 1928

Source: Created by the author with data from the MINVU. Note:*Standards incorporated into the MINVU.

All of these standards are of public interest and help to solve problems of information asymmetry and market failures. For this reason, the active participation of the state is vital in the implementation process on at least two fronts: in increasing subsidies to finance better-quality housing; and supporting the installation of laboratory support with national coverage, which is necessary for the full implementation of the new standards and regulations15.

The process of creating Chilean standards has been very slow. In thirty years, only four regulations related to the energy performance of housing have successfully been incorporated into the OGUC. The adaptation and incorporation of new regulations require means and a substantial learning process, as experience has shown in Chile. In the opinion of experts, the incorporation of the battery of 24 standards currently under study will take several years. Although the study of standards has intensified sharply in the past four years, particularly on energy issues associated with buildings and with a different attitude from the Chilean state, the challenge is still great.

[15] The difficulties faced by the establishment of regulations are not minor. The standards on airtightness classes for buildings in Chile developed by Fondef Project D10 I 1025 quickly became Minvu Technical Standard NTM 011/3 2014, which is currently in the process of public consultation. Class accreditation involves measuring the airtightness of the building with a pressurization test (NCh 3295, equivalent to ASTM E779-10), and the issuance of a certificate by an official laboratory, as a condition for building authorization by the Municipality. The main difficulty currently faced by regulation commissioning is the lack of laboratories prepared to meet the demands that regulations of this type would create. There is installed capacity in only three laboratories to cover a country that extends over 4,200 km. The installation of at least 10 other laboratories in various regions of the country is necessary in order to make the requirement of airtightness classes compulsory. The installation of an energy rating system is facing a similar situation. The preparation of technical staff in the use of the official rating instrument, the official tools MINVU CCLT_CL_V2 and CEV_V_1.0, has taken almost a year. As of January 2014, there were 20 raters trained by MINVU for these purposes. This group should increase to at least 100 during 2014, which is estimated to be the minimum number necessary to install the system at a reasonable cost.

The growing impact of energy costs in all spheres of national life, and what seems to be the existence of a greater environmental awareness in Chilean society, should help to improve the country's current rates of standards renewal and updating.

5.3.2. Thermal Regulations for Housing

The Ministry of Housing and Urban Development incorporated the study of thermal regulations for housing into its action program in 1994 (MINVU, 2002). As a result of the review of experience in Europe and the actions promoted mainly in the academic world, in 2000 Chile became the first country in Latin America to incorporate thermal insulation requirements for housing in its building regulations. At the time, the strategic impact of a measure of this kind in a country like Chile was highly valued, as the nation is energy-dependent to a large extent and has serious quality problems with its residential buildings.

The regulations declared three basic objectives, namely:

a) “To improve the population's quality of life through better thermal comfort and the benefits entailed: greater habitability, better health, less pollution and increased housing durability, etc. ";

b) “To optimize and/or reduce the consumption of fuel allocated to heating and cooling homes" and;

c) To promote and stimulate productive, industrial, academic, professional and applied research activities.

The Technological Division of the Ministry of Housing and Urban Development, DICTEC, was in charge of the study and preparation of the

regulations. Various technical groups, both national and foreign, assisted as consultants throughout the entire process. Of note were groups from the Catholic University of Chile, the University of Concepción, the University of the Bío-Bío, the School of Engineering at the University of Seville, Spain, and the Construction Institute. The last institution in particular, aided in managing and organizing the contributions of different collaborators, both those from the industry and those from academia, in order to arrive at viable proposals in technical, economic and social terms.

The development of the regulations was undertaken in stages. The first stage came into force in 2000 and regulated the maximum thermal transmittance through roofing, along with establishing zoning throughout the country for the purpose of architectural design. The second stage came into force in 2007 and regulated the maximum thermal transmittance through walls, ventilated floors and maximum surface area for windows. Finally, a third stage, which comes into force in 2014, will be voluntary and regulates the general energy performance of housing through a system of energy certification.

The Chilean regulations, in contrast to others more advanced in Europe, deal with only two aspects of the matter: the subdivision of the national territory and the establishment of thermal insulation standards for envelope elements, which are discussed below:

5.3.2.1. Thermal Zoning

The zoning in the thermal regulations subdivides the national territory based on heating degree days, with the aim of defining thermal insulation needs to limit heating demand. The study was entrusted to the Center for Remote

Sensing and to SIG at the Faculty of Agronomy and Forestry Engineering at the Pontifical Catholic University of Chile in 1997 (DTE, 1997).

Figure 5.3 shows the heating degree days zoning at the communal level in the region and the ranges of heating degree days by the zones defined by the thermal regulations.

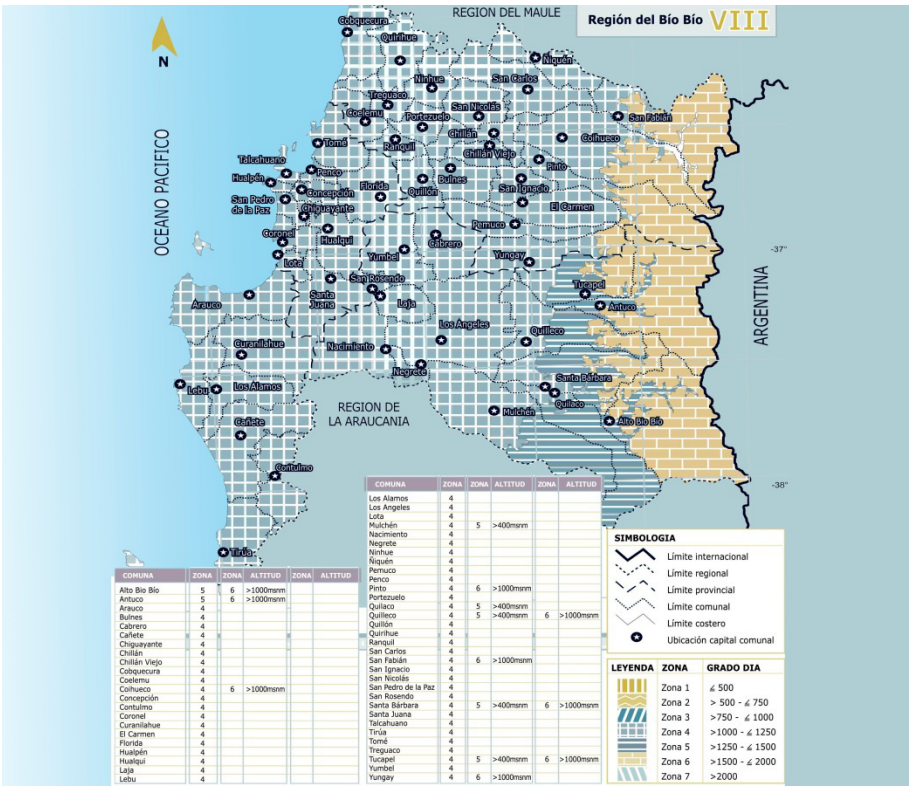


Figure 5.3: Heating degree days zoning at the communal level in the Bío-Bío Region. Source: MINVU, Reglamentación Térmica de Chile.

The zoning takes into consideration the existing administrative divisions at the communal level in Chile, contour intervals every 400m up to two thousand meters and every thousand thereafter, and annual degree day zones

based on temperature information from 55 weather stations defined as the first source of information[16]. With this background, and through the use of mathematical algorithms, a thermal zoning model was developed based on the criterion of annual heating degree days (GDc), with a base temperature of 15 degrees Celsius. The model includes seven zones thought to have relatively homogeneous characteristics for the purposes of regulating thermal protection needs.

The Bío-Bío Region, shown in Figure 5.3, has an area of 37,046.9 km². It includes 54 communes, located up to 1,000 meters above sea level. Zones 4, 5 and 6 are included here, with degree days between 1,000 and 2,000, which determine limit values for the thermal transmittance of walls to be between 1.1 and 1.7 W/m² K. The geographical distances between communes are relatively short; the differences in altitude determine large differences in heating demands.

5.3.2.2. Thermal insulation standards

The regulations set different thermal insulation requirements for roofing, walls and ventilated floors; for windows and for the vertical envelope. These requirements are summarized in tables 5.2 and 5.3.

As can be observed, the Chilean regulations mainly concentrate on the thermal protection of the envelope to limit the transmission of heat through parts of the elements that constitute it. The level of the standard and its correspondence with the specific thermal zone are discussed below.

[16] Much of the information was collected in areas distant from urban centers or from where the majority of the population is concentrated. The information was originally collected for the purpose of agricultural, forestry and especially mining activities, and is used for the purpose of climatic housing zoning with some limitations.

Notwithstanding the foregoing, if compared with other regulatory standards of this type, the national regulations are still basic, whenever:

They do not consider limitations for floor elements in contact with the ground.

They do not differentiate the different cases of element positions, such as walls in contact with the outside air or ground or roofs with air chambers or interspaces.

They do not differentiate by degree of thermal compactness. They make no difference based on the shape, size and form of contact or grouping (detached, semi-detached or attached) that the dwelling might have.

They do not differentiate based on the building's degree of inertia or thermal response.

They do not include requirements to limit air infiltration.

They do not include requirements for solar factors in order to prevent overheating.

They do not include requirements to prevent the occurrence of condensation.

Their guides do not help much with passive building design. They do not promote the exploitation for thermal benefit of variables such as location, volume and shape, ventilation, openings and orientations, grouping, thermal response and others intended to reduce heat loss, effectively use solar gain and minimize instances of overheating.

Table 5.2: Limit values for the thermal transmittance of roofing, walls and ventilated floors, and weighted values of the vertical envelope by thermal zone.

Zona	Techumbre	Muros	Pisos Ventilados	U Ponderado
	W/m2 K	W/m2 K	W/m2 K	W/m2 K
1	0.84	4.0	3.60	-
2	0.60	3.0	0.87	-
3	0.47	1.9	0.70	2.88
4	0.38	1.7	0.60	2.56
5	0.33	1.6	0.50	2.36
6	0.28	1.1	0.39	1.76
7	0.25	0.6	0.32	1.22

Source: MINVU Reglamentación Térmica de Chile

Table 5.3: Limit values for the surface of windows with regards to the surface of vertical walls according to the thermal transmittance of the window.

Zona	% Máximo de Superficie Vidriada Respecto a Paramentos Verticales de la Envolvente		
	Vidrio Monolítico	DVH Doble Vidriado Hermético	
		3.6 W/ $m^2K \geq U > 2.4$ W/ m^2K	$U \leq 2.4$ W/m^2K
1	50%	60%	80%
2	40%	60%	80%
3	25%	60%	80%
4	21%	60%	75%
5	18%	51%	70%
6	14%	37%	55%
7	12%	28%	37%

Source: MINVU Thermal Regulations of Chile

5.3.2.3. Energy certification

The third stage of the regulations involves the installation of a system of energy efficiency certification and labeling in new dwellings, similar in logic to that used by the Energy Performance of Buildings Directive (EPBD) in Europe. This system is currently in the pilot phase and is defining the accreditation process. It is expected to be enabled by the end of 2014 and to be under a voluntary system for only a limited time (MINVU, 2013).

The system uses a procedure to demonstrate the energy efficiency of new dwellings, based on the determination of their energy demand for heating and cooling. The energy quality of the dwelling can be observed by comparing its demand value with that of a reference dwelling that has thermal parameters equal to those defined as minimum requirements for the thermal zone in which the dwelling is located. The system also establishes a labeling system based on the energy consumption for heating, lighting and hot water, using standardized performances for different energy-consuming equipment. The system is currently being implemented on a pilot basis in 50 private real estate projects in different regions of the country.

The system is currently being implemented on a pilot basis in 50 private real estate projects in different regions of the country. To measure and certify, the system uses two tools from the MINVU, which are considered to be official for these purposes: a thermal calculation program for dynamic, multi-zone buildings, the CCTE_CL_V2, developed by the Thermotechnics Group at the School of Engineering at the University of Seville and adapted by Bustamante Huenchuñir (Minvu, 2002); and, a simplified method of calculation, the static worksheet CEV_V1.0 , developed by The Technological Research Institute (IIT) at the University of Concepción (AChEE, et al., 2012).



Figure 5.4: Energy rating system for dwellings. Source: MINVU

Next, the thermal regulations instrument is discussed, taking into account the 20 years of experience since its conception, and going through the operationalization of its various stages, in which this author has participated since its beginning.

The regulations were developed and came into force in stages and with relatively low standards that govern to the present. The reason for this was the industry's almost natural resistance to innovation. This was justified by a generalized idea in the late 1990s that the industry was not prepared to face a scenario with very strict initial thermal insulation requirements.

The process took twenty years, a much longer period of time than originally estimated, with the aggravating circumstance that their impact is not very well evaluated. They meet the stated objectives at the minimum level and, essentially, have helped very little to reduce the energy demand of housing in Chile, at least not in the way that societies require of instruments of this nature nowadays.

Before long, the use of the thermal regulations demonstrated a series of limitations. The most important are summarized as follows:

a) The requirement levels for walls are low; they are incompatible with the optimal minimum energy use needs in the more populated, south central areas of the country.

b) The thermal zoning includes within the same zone localities with very different heating demands, all of which have the same requirements.

c) It does not include important specifications to limit cooling demand, only heating, when in large parts of northern Chile and part of the central zone the most important demands are for cooling.

d) It does not include specifications intended to limit infiltration losses, only transmission losses. The energy certification system assumes the same airtightness characteristics for all buildings in Chile, and the same energy losses due to infiltration for all buildings in the same locality.

The required thermal insulation standards for buildings in Chile are low. The thermal insulation requirements for walls especially cannot be compared either with European ordinances that govern in comparable climates, or with the standards that some studies in Chile have recommended for several decades (Rodriguez, G. 1973; Bobadilla, A. and others 1986; Bobadilla, A. and others, 1991; Bustamante, W., 2010; D'Alençon, R. 2010; CITEC UBB, 2012a). These standards are presented comparatively in chapter 1, Table 1.3.

What explains these low standards?

The greatest volume of buildings in Chile is built with brick masonry and concrete. Historically, between 70% and 80% of residential construction has been built with these materials, based on simple walls that do not exceed 20

cm in thickness. With these solutions, the thermal transmittance for walls is not less than 1.8 W/m²K. This reference, a typical condition of the walls traditionally designed and manufactured in Chile, determined the requirement level adopted by the thermal regulations in 2007.

The criterion that prevailed was to move away as little as possible from that reference in order to use, hopefully without changes, the same solutions and, in cases that this is not possible, to be able to use the same solutions with minimum thermal reinforcements so as to keep costs competitive. This strategy was imposed by the powerful cement and concrete industry in Chile to face the competition from light wood construction systems and other systems that were naturally better prepared to cope with thermal insulation requirements. This strategy was favored by the Chilean state, which at the time was more concerned with increasing the number of housing solutions than their quality.

The diagnostic reported in chapter 3 shows that, at a national level, dwellings demand twice the necessary energy to provide thermal comfort services. An important part of the cause derives from the situation explained: the low standard of thermal insulation that is required in housing in the south central and southern zones, which are the most populated in the country. The standards in these areas should be improved, so as to move from the current levels, 1.9 - 1.7 - 1.6 W/m²K, required in the territory covered by zones 3, 4 and 5 respectively, which contain more than 80% of the population, to levels between 0.4 and 0.6 W/m²K. These substantive changes are economically and socially justified (MINVU, 2013).

Meanwhile, thermal zoning presents problems derived from the same criterion that was used to create it: a subdivision based on heating degree days calculated with the average temperatures of the localities. Zoning

conceptualized in this way cannot differentiate between localities that have similar average temperatures but different levels of oscillation. It classifies within the same zone, with the same thermal insulation requirements, localities with heating demands that can be very different, which generates significant errors in the estimation of energy demand in many localities[17].

Table 5.4 shows the differences in thermal parameters between the climate zoning and the thermal zoning. The thermal zoning, which only differentiates on the basis of average temperatures, classifies in the same area and with similar requirements coastal localities such as Concepción, with other half-way points such as the cities of Talca and Linares, and with others in Andean foothill areas, such as Potrerillos. These zones have very different climates and energy demands, which are given better consideration in the zoning proposed by standard NCh 1079.

Table 5.4: Thermal Oscillation, average temperature and monthly degree-days base temperature 15°C using data from NCh 1079 ordered according to thermal zone.

Zona Térmica	Zona Climática NCh 1079	Localidad	Oscilación térmica Enero (° C)	Oscilación térmica Julio (° C)	T. media Enero (° C)	T. media Julio (° C)	Grados-día base 15° C mensuales
Zona 4	CI	Curicó	18.7	8.9	19.9	7.2	1147
Zona 4	CI	Talca	18.9	11.4	20.3	7.6	965
Zona 4	CI	Linares	17.8	10.2	19.6	6.4	1075
Zona 4	CI	Cauquenes	17.1	9.0	21.0	8.9	894
Zona 4	CI	Chillan	17.8	8.4	19.1	7.3	1175
Zona 4	SL	Talcahuano	7.7	6.8	sin dato	sin dato	sin dato
Zona 4	SL	Concepción	12.3	7.3	16.3	8.8	1100
Zona 4	SI	Los Ángeles	16.9	8.8	sin dato	sin dato	sin dato
Zona 4	AD	Potrerillos	8.5	9.1	sin dato	sin dato	sin dato

Source: Created by the author with data from the MINVU

[17] For example, it classifies in the same zone the cities of Calama (Latitude -22.46°, -68.91° and 2,270 masl) with average annual daily oscillations of 22°C, and Valparaiso (Latitude -33.06°, -71.63° and 41 masl) with oscillations of 6.3°C. 1,208 km separate these two cities and the same thermal insulation requirements apply to both.

Due to the problems described above, in early 2013 the Ministry of Housing and Urban Development convened a committee of experts to review and perfect the regulations. Essentially, this was to develop a new territorial subdivision strategy, along with a modification proposal for the standards of thermal insulation and classes of building airtightness, which is the first time that the variable of airtightness was considered in Chile (MINVU, 2014). The committee, with the counsel of Waldo Bustamante, developed two new technical standards for the Ministry, the requirement standards NTM 011/2 2014 and NTM 011/3 2014, which were put out for public consultation in March 2014. The scientific basis for and foundation of the proposals for new standards and zoning are gathered from investigations carried out in recent years in Chile, as can be seen in the same report and among which is included this thesis[18].

The new subdivision proposal is likewise based on the temperature variable, but it also incorporates the daily thermal oscillation as a differentiation criterion. It includes nine zones, two more than the current thermal zoning, categorized with letters from A to I. The main differences, as explained by the document on the topic, "are due to the definition of 3 entirely coastal zones (A, C and E); the definition of 2 zones (H and I) in the extreme south

[18] The proposal for airtightness classes uses the results of Fondef project D10 I 1025 as a main source of reference, as has been pointed out. The proposal for new thermal insulation standards uses as its main references the standard NCh 1079, which was created based on work carried out by Rodríguez in the 1970s; the Standardized Reference Terms (TDRe) of the Architecture Directorate at the Ministry of Public Works, drawn up by CITEC UBB; The Construction Institute's, Passive Design and Energy Efficiency in Public Buildings Manual, created by CITEC UBB in the context of the development of Innova Chile project Number 09 CN14-5707; The Ministry of Housing's, Design Manual for Energy Efficiency in Social Housing, prepared by the School of Architecture at the Catholic University of Chile; the Chilean Energy Efficiency Agency's, Guide to Energy Efficiency for Educational Establishments, developed by CITEC UBB; and, from the same agency, the Energy Efficiency Guide for Health Care Facilities, prepared by the consortium made up of the consultants Arquiambiente and Aiguasol. From this thesis, the results of the energy quality baseline and the study on gaps by province and country are used to support the proposed class limit levels by province.

of the country (south of Chiloé island); the expansion of the Andean zone and the Andean foothill zone (G) in an approximation closer to the Andean Zone in NCh 1079:2008 than to zone 7 in the R.T; and finally, the clear separation between the zones corresponding to the northern, central, southern and extreme southern sectors of the country." (MINVU, 2013).

Table 5.5: Proposal of new thermal insulation and airtightness standards

Zona Térmica	Complejo de Techumbre		Complejo de muro		Complejo de piso		Complejo de puerta		Clase hermeticidad de aire
	U	RT	U	RT	U	RT	U	RT	50 Pa
	W/(m2 K)	(m2 K) W	W/(m2 K)	(m2 K) W	W/(m2 K)	(m2 K) W	W/(m2 K)	(m2 K) W	ACH
A	0,84	1,19	2,10	0,48	3,60	0,28	--	--	--
B	0,47	2,13	0,50	2,00	0,70	1,43	1,00	1,00	6,00
C	0,47	2,13	0,50	1,25	0,87	1,15	1,20	0,83	9,00
D	0,38	2,63	0,60	1,67	0,70	1,43	1,20	0,83	8,00
E	0,33	3,03	0,50	2,00	0,60	1,67	1,00	1,00	8,00
F	0,28	3,57	0,45	2,22	0,50	2,00	1,00	1,00	7,00
G	0,25	4,00	0,30	3,33	0,32	3,13	1,00	1,00	4,00
H	0,28	3,57	0,40	2,50	0,39	2,56	0,80	1,25	6,00
I	0,25	4,00	0,35	2,86	0,32	3,13	0,80	1,25	4,00

Source: Created by the author with NTM 11/03 data

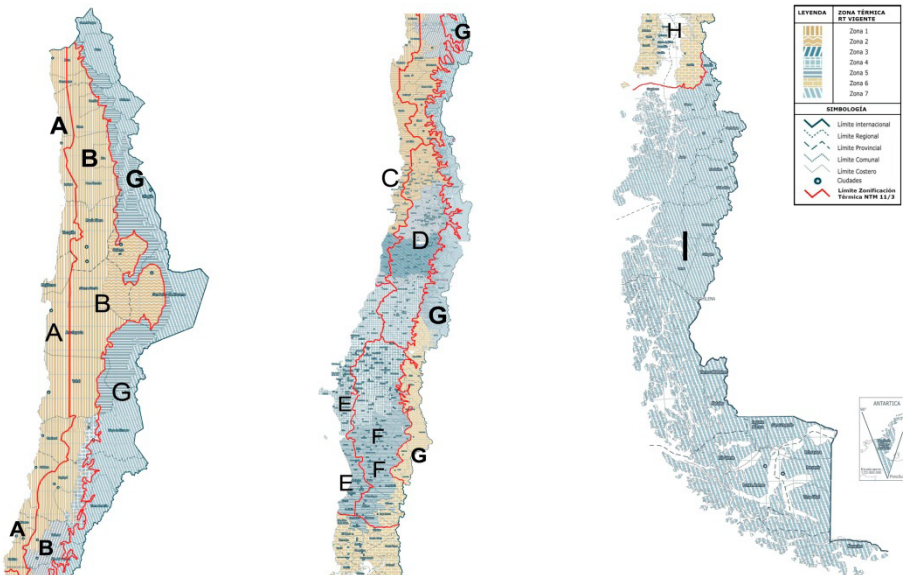


Figure 5.5: New territorial subdivision proposal. Source: Minvu Technical Standard 11/03

Table 5.5 presents the description of the proposed new thermal zones. Figure 5.5 shows the graphical representation of the new zoning. With minor differences, is virtually the same subdivision, also of nine zones, set out by NCh 1079. The proposal takes into consideration in an improved manner the variable of thermal oscillation, which is clearly visible on the east-west axis from the Pacific Ocean to the Andes Mountains; and the average temperature differences that occur on the country's north-south axis.

The new territorial subdivision proposal would enable the improved adjustment of thermal insulation requirements to the climatic needs in each locality and would consequently reduce heating demands in those localities that had been incorrectly classified. However, for reasons of simplicity, use of the same subdivision is proposed in order to set airtightness requirements, which is not correct and leads to errors that may be significant.

The airtightness standards are the reflection of a building's capacity to limit the air infiltration generated by pressure differences that induce airflow through the envelope. These pressure differences can be produced by the action of the wind on facades and/or by convective effects caused by thermal differentials (stack effect). In Chile, wind pressure is more important in the occurrence of air infiltration and it is not necessarily related to temperature and thermal oscillation throughout the country (Bobadilla et al, 2014). The variable of wind speed can even generate greater distortion than that created by temperature oscillation under the current thermal zoning[19]; which was

[19] Fondef Project D10 I 1025, which acts as the basis to set out the proposition for airtightness classes, proposes a subdivision by provincial capital for the effects of airtightness requirements.
The criterion finally adopted combines two fundamental conditions taken in part from work with similar purposes carried out by Sherman in the United States in the 1980s. Hence, the class of airtightness by province must be such that its energy load does not exceed 40 kWh/m²year and at least 10% of current stock must pertain to this class. Following this criterion, the project proposes limit classes for each of the

made known to the authorities during the standard's present consultation process.

With regard to the third stage of the regulations, the greatest difficulties encountered in the current installation process arise from the design of the tools used for rating energy efficiency in dwellings. Two official tools are used: one, the static calculation worksheet CEV_V_1.0, and another, the dynamic analysis software CCLT_CL_V2. Both tools can be used interchangeably, except when window surface area exceeds 30% of vertical surface area; in which case, only the dynamic software should be used. Both tools usually do not produce the same results, which confuses and generates credibility conflicts and, more importantly, both tools use a fixed value of air renewal per hour as standardized infiltration, which incorrectly assumes that all buildings have the same airtightness and the same energy losses due to infiltration within the same locality. This value is a structural part of the tool and is impossible to modify. This is a limitation of the tools that affects their ability to estimate energy quality; for this reason, it generates distortions in the compared quality assessment between one alternative and another. Similarly, the rating itself is altered whenever the building in question is compared with a reference building, with only optimized heat transfer parameters. This occurs because the tool also assumes the same airtightness for the reference building. Therefore, determining the real impact of envelope airtightness on the energy quality of buildings cannot be achieved. This is a serious limitation of the tools, considering the great influence of air infiltration on the energy performance of housing, as demonstrated in the diagnostic.

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54 provincial capitals. The physical geography of the nation, its particular orography and topography, and the altitude and nature of the land, generate microclimates and wind regimes ranging from almost permanently calm in some localities to nearly extreme situations in others within the same zone. In consequence, what seems to be the most appropriate for the purpose of setting requirements is to establish the province rather than a thermal zone as the territorial unit.

Finally, it should be noted that at the time, the thermal regulations arose as part of a policy leading to increased quality and housing standards, and to optimize energy consumption in buildings; nevertheless, in practice, it serves and is only used to limit heating demand, and not at the level it should, as demonstrated in the diagnostic. It does not include limits for cooling demand, which can reach relatively important levels in the country's first two thermal zones, and in many apartment buildings from the first to the fourth zone (Encinas, F. 2012).

5.4. Itemized Technical List for Construction

The National Itemized Technical List for Construction is the governing document for building. It was developed by the MINVU for dwellings financed with funds from the state's Solidarity Fund for Housing Choice. It was approved by Exempt Resolution Number 9020 (Housing and Urban Planning) in November 2012 and defines the minimum technical specification standards that must be met by housing projects or by construction projects in the previously mentioned housing programs. These itemized technical lists are based on the OGUC, but incorporate additional stipulations to address improperly covered or missing aspects in the OGUC, specifically, related with condensation and ventilation, which are aspects that are not addressed in the OGUC (MINVU, 2012).

With regard to these matters, it prescribes exactly the following:

"For each particular case, according to geographical location, design (construction system and degree of ventilation) and dwelling use (generation of water vapor and heat) in walls, the elimination of the risk of superficial

and interstitial condensation should be ensured. The analysis of the risk of condensation must be performed on the basis of standard NCh 1973, and the water vapor transmission values of the materials must be supported with tests based on standard NCh 2457."

- Should vapor barriers be incorporated to eliminate the risk of interstitial condensation, they must be continuous and installed under or over the interior facing.
- When a vapor barrier is installed under the interior facing, this barrier will not be 100% impermeable to water vapour transmission.
- In the case that paint is used as a vapor barrier, it can only be applied over the interior facing.
- Walls should include barriers against constant moisture under the external facing. In cases where there is no exterior cladding, impermeability to water and permeability to water vapor must be ensured in walls. Whichever solution is adopted must be impermeable to water and rain, and must allow interior water vapor to escape.
- In no case can exterior cladding nullify the effect of the water vapor permeability of a vapor barrier.
- In bathrooms and kitchens, extractor fans must be installed. In the case that they are not used, passive systems must be designed that ensure the minimum renewals required to eliminate vapor production within dwellings, according to calculations."

This is a typical prescriptive specification that recommends what to do and how to do it, without any reference to objectives or performance standards that can feasibly be verified and checked. This specification design does not assist with the goal of advancing the development of dwellings characterized by low demand for energy resources; that involve lower operational costs for

their users; and that achieve better thermal comfort, acoustic, light and air quality standards. For these purposes, the new specification approaches and ordinances based on performance are the most appropriate, and it is a change that should be made in Chile considering its current state of development[20].

Article 3 of Exempt Resolution Number 9020, which created the National Itemized Technical List for Construction, leaves open the possibility that "prior written authorization of the MINVU may approve regional itemized technical lists for construction that should be sanctioned by resolution of the respective Regional Secretaries of the Ministry of Housing and Urban Planning."

The need to complement content, and add requirements and different standards in relation to particular regional characteristics is acknowledged here. However, no region should decrease the minimum standards established in the National Itemized Technical List for Construction.

As of January 2014, no region had managed to develop a regional itemized technical list of its own and it is urgent to do so. The main quality problems associated with a building's hygrothermal behavior are largely explained by the absence of clear and objective standards and requirements that should be expressed in a document of this nature.

[20] The approach based on performances, objectives or the provision of services is understood as an approach focused on the set of objectively identifiable qualitative or quantitative construction characteristics that contribute to determining their aptitude for responding to the different functions for which they were designed. These instruments include explicit statements regarding goals and objectives that reflect society's desires and expectations; requirements and specific demands that both materials and elements must comply with to achieve these expected objectives; the performance criteria for deciding when a solution is satisfactory; and the methods that are used to demonstrate compliance of the requirements. Currently, 26 of the 31 OECD member countries and many others already have construction ordinances with an approach focused on services.

5.5. Chapter Conclusions and Comments

Upon reviewing the creation of standards, ordinances and regulations applicable to residential construction in Chile during the period 1981-2012, the following was concluded:

The creation of standards aimed at improving the energy quality of housing in Chile shows important shortcomings; they require changes in their organization and planning. The state must assume a more active role in the development of standards, in particular with those of public interest as are many that are intended to establish building standards and requirements. The work of standards creation cannot be dependent solely upon the interests of the industry which finances it, as occurs in Chile.

The different technical standards provide the necessary support and foundation for the regulations "to seek to attain optimal levels of the required properties or characteristics of a product, which enable it to fulfil its use function in a satisfactory manner;" in this way standards help to improve quality, safety and industrial competitiveness.

How do standards in Chile help to improve energy quality in its residential buildings? Energy quality is understood as specified in previous chapters: "the condition that is obtained when appropriate levels of indoor climate are achieved for users with limited or minimum energy use." This is known to be a capability inherent to a building's design, which must follow certain guidelines and criteria, and that their regulation is necessary to achieve this condition.

They help very little not at all. Only six standards make up the regulatory framework of the thermal regulations in Chile: two calculation standards,

three testing standards, and one on zoning and design recommendations. In the country's present state of development, and considering international practice in this regard, there is an urgent need to incorporate into the regulations hygrothermal, air quality, ventilation, air and water permeability, and energy performance standards among others. It will be impossible to make progress in the improvement of the building stock if existing regulatory support is not previously improved.

The study of standards in Chile has increased in recent years. A significant volume of standards is currently under study, and without considering how questionable this work might be, as has been pointed out, this is not the issue. The issue is the incorporation of the standards into the regulations. In Chile, technical standards are voluntary and become compulsory when they are included in a mandatory regulation passed by the authorities. In the past 30 years, only 6 standards have become compulsory and currently 24 are being studied for incorporation into the thermal regulations or another regulation.

There are three elements that basically explain this slow process of incorporating standards into the regulations and the "voluntary use" status of the majority of standards in Chile:

The first is related to the lack of technical support at the laboratory level to support the process of installing testing standards especially. The installed capacity in Chile is still limited; there is need for a greater number of laboratories, which are better distributed throughout the country, in order to meet demands for verification of conformity services in a timely and efficient manner. Currently, the country's geography also creates a coverage problem: virtually 100% of the facilities available are located in the central

zone and the country stretches 2,000 km to the north and south of these centers.

The second issue is human resources. There are not sufficient human resources in all the fields required by standards implementation; personnel need to be trained beforehand, both for laboratories and professionals dedicated to the control and supervision of more complex requirements. In the same way, strengthening the national system of laboratory and specialist accreditation is required, in order to organize the processes of control and supervision of designs, materials and buildings under construction.

The third issue, and not the least, is the resistance from the industry to incorporating standards into the regulations, which would mean increasing energy quality requirements. Traditional brick and concrete construction in Chile, which historically has occupied close to 80% of the market, is not prepared for more demanding thermal insulation requirements than the current ones, due to the building type and designs used. The new prefabricated construction is prepared but has not yet significantly impacted the market, among other reasons because of the low value the market gives to thermal protection in construction, and because the current regulatory requirements do not allow it to differentiate itself as a solution for thermal insulation.

In 2000, the thermal regulations fulfilled the great purpose of officially installing the theme of housing energy quality in Chile. In discourse, these regulations were linked to the purposes of "improving the quality of life of the population" and "optimizing and/or reducing fuel consumption intended for the heating and cooling dwellings."

The study of the establishment and application of the regulations recognizes some merit in this sense, but very limited. The regulations have failed in one of their main objectives: to help to limit the energy demand of dwellings in Chile. The housing stock, as evidenced by the diagnostic study, demands double the energy it should require to provide comfort conditions to its users; this situation is mainly explained by the influence of the regulations. The standards that the regulations set, and which are required of the industry, are very low, and the thermal zoning does not properly adapt insulation requirements to climatic requirements. In this way, their guides and dictates do not help in reducing energy consumption in dwellings. For these reasons it is urgent to update said instrument.

Carrying out this work, which is currently underway, raises at least two fundamental questions that the country should know how to answer: What are the minimum thermal protection requirements? And how are these requirements, as well as the regulatory controls to ensure their compliance, established?

There is no simple answer, whenever complexly interacting social, cultural and economic variables are involved that directly relate to society's economic and technological capacity, its degree of maturity and quality expectations. In the coming years, the country should move forward in defining and agreeing upon these issues, to finally achieve a proper regulatory framework, bearing in mind the social demands of optimal minimum use and sustainable energy use in buildings, which are imposed today in all modern societies.

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6.0. EVOLUTION AND STATE OF THE BUILDING PHYSICS LABORATORY INFRASTRUCTURE

In this chapter, advances in the creation of scientific-technological infrastructure in the area of building physics in Chile are presented and discussed. In general, these laboratory facilities drive processes of knowledge-, technologies- and standards-creation in the area of habitat, energy and housing. Important milestones in the installation of laboratories in Chile, the existing capacity and the centers where they are found are explained. The chapter concludes with an analysis of the current and future demand for laboratory support, which derives from the creation of new technical regulations and from research in areas yet to be covered. From this analysis, the needs for new laboratory infrastructure in Chile are deduced for the next 10 years.

6.1. Units of Experimental Work in Building Physics

Buildings are essential components of society and the economy. They provide spaces as well as safe and protected environments so that people can live, work, study, entertain themselves, etc. On the other hand, building, operating and maintaining buildings demand an important part of the budget of families and nations in many parts of the world. For these reasons, the political and legal systems of many countries require their buildings to have socially acceptable energy performances; this means, as defined in this thesis: optimal minimum energy consumption, without diminishing indoor comfort and with low environmental impact. To achieve this objective, knowledge of building physics is fundamental.

Interest in the study of building physics has had strong momentum in the last two decades in Chile. This interest has been motivated by several reasons; the first and main reason derives from the need to improve the energy quality of buildings and respond to multiple quality problems that have historically affected housing in Chile. For these needs, building physics serves to support technical expertise and development work that aims to develop new materials, technical regulations and standards.

Emerging social phenomena have had an important influence on the development of the discipline: greater environmental comfort aspirations for buildings users and growing social awareness of the impact that buildings have on the environment. Today, society requires more energy efficient, safe and sustainable buildings, and increasingly demands those requirements as rights.

Building physics is a branch of construction science dedicated to the study of diverse phenomena and physical processes to which constructions are exposed and that affect their performance and quality. More precisely, Hugo Hens defines it as an "applied science that studies the hygrothermal and acoustic properties, and those related to the light of construction elements (roofs, facades, windows, partitions, etc.) rooms, parts of buildings and buildings" (Hens, 2007). It is the base science for research into the development of new products and technological solutions intended to control, regulate and, from time to time, inhibit those processes, especially heat, air and moisture transfer through building envelopes, which is known as "HAM Transport" (Kunzel, 1997).

Thus, lines of work in the thermal, water, acoustic and solar behavior (light and heat) of materials, construction elements and buildings as a whole, are understood to be within the domain of building physics. Also within the

same area can be found topics related to ventilation, the environmental comfort of precincts and building airtightness. In spite of the fact that the concept of building physics is broader, this thesis assumes that domain, so as to link this science with the need for experimental facilities to drive processes of knowledge and technology creation, in the area of habitat and energy linked to residential construction in Chile.

The development of experimental practice in building physics was motivated in the beginning by the demands for certification and standardization of materials and elements. This activity obliged the development of testing techniques and procedures to measure and evaluate physical characteristics and required features. Subsequently, from the middle of the 1970s on, this experimental activity became more strongly related with the development of models that attempted to predict energy consumption in buildings and helped both to validate simulation models and obtain the properties of materials or building components that serve as supplies in the models. The latter is due to the fact that a model cannot simulate real world situations without using reliable information on material properties. On another front, the experimental work serves to study phenomena that are not accessible through analytic or numerical calculation, which because of their complex nature, require experimental observation.

6.2. Evolution and State of Building Physics Laboratory Infrastructure

The objective of this chapter is to know the installed capacity of building physics laboratory infrastructure, and relate it to current and future needs for research and the creation of regulations related to the area, in order to determine the gaps and, finally need for new investments in infrastructure.

As another, but not lesser objective, this chapter also aims to understand the infrastructure installation process in this discipline in Chile and identify its main milestones.

For the purposes indicated, primary and secondary sources of information were used. These included: interviews and surveys with the executives of the primary units that work in the area; public information available on institutional web pages; and the knowledge of this author, as the creator and director of one of the units where most of the available infrastructure in the country for experimental activities in building physics is situated.

The cadastre carried out showed that the building physics laboratory infrastructure is basically concentrated in four research centers: in the Center for Research in Construction Technologies at the University of the Bío-Bío, CITEC UBB, which has the greatest volume; the Institute for Research and Testing of Materials at the University of Chile, IDIEM; the Directorate of Research in Science and Technology at the Catholic University of Chile, DICTUC UC; and the Center for Research on Southern Housing at Austral University, CIVA.

These four centers concentrate more than 95% of the available experimental facilities of this kind in the country. 80% approximately, is found at CITEC UBB and IDIEM. IDIEM and DICTUC are centers that cover multiple areas of engineering, architecture and construction and are present throughout the country. CITEC UBB and CIVA are centers specializing in specific fields of building physics. IDIEM mainly works in the areas of heat, water and acoustics at different levels; DICTUC in the area of heat; CIVA, mainly in the area of acoustics; and CITEC UBB in the areas of heat, water, acoustics, lighting and ventilation.

They are recognized as organized units that make regular use of their experimental facilities in published research activities and in consultancy services and diverse studies for institutions and for the industry. Only three of these centers maintain areas dedicated to building physics that are registered in the Ministry of Housing and Urban Planning's Official Register of Technical Control Laboratories for Construction Quality: CITEC UBB, IDIEM and DICTUC, and the last only in the area of thermal insulation of materials.[21]

Other experimental capacities, considered to be of lesser importance and/or in the process of creation and organization, are found at DECON UC, the Department of Civil Construction at the University of the Frontera in Temuco and in the Department of Mechanical Engineering at the University of Concepción.

Table 6.1 illustrates the installed capacities for experimental activities in building physics in the four laboratories cited, with reference to the main regulations and installed testing techniques.

[21] As of January 2014, the Official Register of Technical Control Laboratories is made up of 351 laboratories accredited according to NCh-ISO 17025. Of 2005, which is necessary to belong to the register. The area registered is environmental conditioning and the specific controls are materials conductivity (NCh 850) and the thermal transmittance of elements (NCh 851). The areas of quality included in the the register are: Steel (5 laboratories); Environmental conditioning (2 laboratories); Aggregates (66 laboratories); Asphalts and asphalt mixtures (40 laboratories); Cement (4 laboratories); Fire behavior (2 laboratories); Elements and components (33 laboratories); Construction physics-chemistry (60 laboratories); Concrete and mortar (69 laboratories); Wood (3 laboratories); Soil mechanics (67 laboratories). The structure of areas and laboratories by area show the low and practically non-existent attention paid to quality problems associated with the hygrothermal behavior of housing in Chile.

Figure 6.1 shows, on a time scale, the process of installation of experimental facilities in Chile, its main milestones, and events that justified the creation of the laboratories.

Table 6.1: Installed facilities for experimental activities in building physics in the main centers that work in this discipline in Chile.

CAMPOS		NIVEL	CENTROS DE INVESTIGACIÓN				PRINCIPALES TÉCNICAS/NORMAS UTILIZADAS
			CITEC UBB	DICTUC	IDIEM	CIVA	
Higrotérmica							
Materiales	Térmica	Laboratorio	X	X	X		NCh 850- NCh2457- ASTM 1046- CIBSE(A,B) - ANSI/ASHRAE 62.1 - RITCH - RITE- NCh 891 - NCh 851 - ASTM 1046 - NCh 892 - NCh2821 – ASTM E-514 - ASTM 1060 - ASTM C1046 - EN 13187 - ISO 6781 - CIBSE(A,B) - ANSI/ASHRAE 62.1 - RITCH - RITE - NCh2821 – ASTM E-514 - NCh1973 - NCh2457 - NCh853 - NCh 2791 - NCh3136/1 - NCh3137/1 - NCh3137/2 - NCh3076/1 - NCh3076/2 - NCh3117 - NCh2251 - NCh 849 - NCh 3078 - NCh 3077
		In situ	X				
	Hídrica	Laboratorio	X		X		
		In situ	X		X		
	Óptica	Laboratorio					
		In situ					
Elementos	Térmica	Laboratorio	X	X	X		
		In situ	X				
	Hídrica	Laboratorio	X		X		
		In situ	X		X		
	Óptica	Laboratorio					
		In situ	X				
Edificios	Térmica	In situ	X	X	X	X	
	Hídrica	In situ	X				
	Óptica	In situ					
Acústica							
Materiales		Laboratorio	X		X	X	ISO 10534-1 - NCh 2786 (ISO 140-3), ISO 140-6 - NCh 2785 (ISO 140-4), ISO 140-7 - NCh 2785 (ISO 140-4) - NCh 2803 - ISO 140-5 - NCh 352Of6 - NCh 352/1 - ISO 3382 partes 1, 2 y 3, (D.S.Nº 38/11 MMA - ISO 1996 partes 1 y 2 - NCh 2803 - ISO 16032
		In situ	X		X	X	
Elementos		Laboratorio	X		X	X	
		In situ	X		X	X	
Recintos		In situ	X		X	X	
Iluminación							
Materiales		Laboratorio					Simulación computacional dinámica mediante Radiance. Monitorización de variables lumínicas según protocolo definido.
		In situ	X		X		
Elementos		Laboratorio					
		In situ	X		X		
Recintos		In situ	X		X		
Ventilación							
Recintos		Laboratorio					CIBSE(A,B) - ANSI/ASHRAE 62.1 - RITCH - RITE, ANSI/ASHRAE 62.2
		In situ	X				
Hermeticidad							
Elementos		Laboratorio					UNE EN 13829 - NCh 891 - ASTM c1601-11 - UNE-EN 1928
Recintos		In situ	X	X			

Source: Created by the author

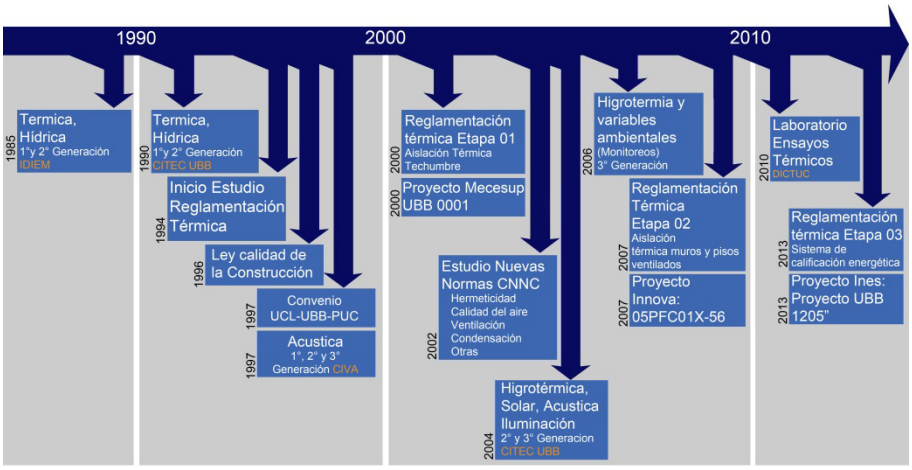


Figure 6.1: Milestones in the process of installing building physics laboratories in Chile. Source: Created by the author

Upon reviewing the record of the process of installation of building physics laboratories in Chile, different origins and motivations are evident in the diverse institutions in which they are found. Although all have different priorities, they are conceived to serve as support tools for experimental research and provide services for the industry and disciplinary training in Chile.

They were created to give more immediate answers to social and technical needs that arose in the last two decades in the country; basically needs derived from obligations imposed by the Quality Construction Law in 1996; needs for support for the installation of technical standards and the thermal regulations of 2000; and to support processes of development and/or adaptation of new materials, elements and construction systems motivated by the thermal regulations.

From the analysis of the testing types and levels that are currently possible at the existing laboratories, capacities were detected for the study of first,

second and third generation properties in the different centers under study, which are explained as follows:

First generation capacities are understood as those that can be used for the study of specific material properties under controlled laboratory conditions. They were the first to be installed in Chile and in 1980, IDIEM at the University of Chile became the first institution in the country dedicated to the study of building physics with the support of experimental tools. It installed the equipment and techniques to measure some of the material properties of greatest interest in building physics at that time, such as thermal conductivity, specific heat, moisture absorption and vapor permeability.

In the 1990s, CITEC UBB installed the same techniques and in successive years, others to measure the air permeability of materials and the thermal and hygroscopic properties of materials in situ. Recently in the middle of the last decade, DICTUC began to make incursions into the area with facilities exclusively for the thermal analysis of construction materials and elements.

Second generation capacities are those that can be used for the experimental study of construction elements under controlled laboratory conditions; these facilities serve to make hydrological, thermal, acoustic and light characterizations of life-size samples of construction elements. They developed in response to the need to study and certify performances, no longer of materials, but of complex elements, as required by thermal and acoustic regulations that were imposed at the time. They also arose to contrast performance hypotheses of new types of panels, walls, roofs, floors, etc., in the context of R&D activities and of the adoption of new materials and construction systems that began to be introduced into the country in the

middle of the last decade. These products needed to be tested and certified in the country's official laboratories.

Currently, IDIEM and CITEC UBB mainly possess all or some capacities of this type, as illustrated by Table 6.1. The first facilities of this type date from the 1980s and, from that date on, more have progressively incorporate over time in response to situational needs. Thermal and acoustic laboratories for laboratory tests on elements are available in three centers; for lighting in 2 centers; and for facade and window watertightness, for laboratory tests and in situ, only at CITEC UBB.

The third generation experimental capacities are those that are used for more complex experimental studies of the hygrothermal, acoustic and lighting characterization of life-sized elements and buildings, under real climate conditions. They developed in answer to the need to study and certify, in this case, performances neither of materials nor of elements, but of much more complex systems, such as parts of buildings and buildings in their entirety. They arose as a need when public building contracts in Chile started to require proof of the global behavior of buildings and their facilities. In addition, these needs in Chile emerged in the context of research and development projects on new construction systems to build dwellings, whose environmental and energy attributes needed to be measured and certified to obtain authorization for use in the country, which is given by MINVU's DITEC. For example, they include techniques to monitor the energy demand and consumption of buildings, which are oriented toward evaluating energy efficiency; techniques for monitoring hygrothermal, lightning and acoustic conditions, and environmental air quality; and techniques to evaluate airtightness and the ventilation of enclosures and buildings, among others.

Laboratories and techniques of this type for processes in the area of acoustics are available in three centers in Chile, and for light analysis in at least five centers. Installed techniques with equipment and personnel qualified to perform real-time energy and environmental monitoring for prolonged periods, which are of greatest interest for the purposes of energy optimization in the housing stock at present, and are mainly available in CITEC UBB and IDIEM.

The primary facilities available in Chile to carry out experimental activities in building physics are currently found at CITEC UBB. This center is the result of the natural evolution of a research group that began its activities in the 1980s. Nowadays a center for research and technological transfer, over the course of the last 20 years the group has undertaken numerous Fondecyt, Fontec, Fondef, Innova Bío-Bío, and Innova Chile-type research projects, among others, resulting in the creation of new products and services on the market, patents and the formation of capacities.

CITEC UBB has financed all its infrastructure through competitive public funding opportunities. In the last 20 years, three of the four technological infrastructure projects for the creation and strengthening of laboratories in Chile in the area of building have been awarded to CITEC UBB. Presented in 2013, with financing from the Department of Education and currently underway, the last project will invest $6 million USD in R&D, human resources training and new laboratory infrastructure projects "to meet the current and future demands for activities that promote habitat and sustainable construction," which is the core idea of this project. This project, along with two previous projects of similar magnitude which will be explained later, are considered important milestones in the laboratory capacities installation process in the area of building physics in Chile.

As explained further on, since the 1990s CITEC UBB has received consultancy and international collaboration from the Architecture and Climate group at the Catholic University of Leuven.

6.3. Milestones in the Process of Experimental Capacities Installation

The creation of laboratories in Chile has several milestones or historic events. Among the most important are the Construction Quality Law, the thermal regulations, emblematic infrastructure projects that enabled the financing of laboratories, international cooperation projects, and other diverse initiatives to create and/or update technical regulations.

The most important milestones in this process of capacities construction are explained below:

6.3.1. UCL-UBB-PUC Cooperation Agreement

Dating from 1997, the international cooperation agreement between the Catholic University of Leuven, the University of the Bío-Bío and the Catholic University of Chile, was established for the creation and development of an architecture and sustainable construction research team in Chile under the consultancy and direction of the Architecture and Climate group (UCL, 1997).

In terms of specific commitments, the cooperation agreement provided for: training of human resources; development of notable research programs focused on current and future local knowledge needs; and production of basic technical documents for professional teaching, and the promotion of and creation of awareness about this area, among the most important tasks.

To date, the development of this agreement has enabled the training of 2 Masters and 7 Doctors of the specialty in Chile, and the development of research programs that have had a strong impact on the academic and industrial activity in construction[22].

Through this agreement, international consultancy was provided in 2004 for the installation of a hygrothermal test module (MPHT) and a solar test module (MPST) at CITEC UBB[23]. The MPHT module is used to analyze transportation phenomena through life-sized construction elements under real climatic conditions; it is based on the experience carried out in the VLIET Test Building project at the Bouwfysica van K.U. Laboratorium Leuven, Belgium (Janssens, A. & H. Hens 2000). Meanwhile, the MPST module is used to analyze the passive solar advantage of life-sized building components; it is based on the experience in the construction and use of passive solar component testing modules in the European Commission's PASSYS project (Wouters and et al, 1994). Both modules currently constitute the most advanced facilities for studies of hygrothermal problems and are one of a kind in Chile.

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[22] Eight of the eleven projects in the area approved since the creation of the Scientific and Technological Development Fund (FONDEF), the most important in Chile and one of the most competitive in Latin America, have been awarded to academics trained at the Catholic University of Leuven under the auspices of this international cooperation project.

[23] In the framework of this international cooperation agreement, this author carried out his master's degree in 2002 and now his doctoral degree program. The master's degree thesis was about the "development of test modules for experimental work in physics applied to buildings in Chile." In said work, the technical information necessary to design, implement and operate test modules or "Test Cells," which were finally built in 2004. The modules took into consideration developments in experimental work in the discipline on a global scale and also the training and research needs in the country at that time. The main source of reference was the VLIET Test Building project, developed by the Bouwfysica Van de K.U. Laboratorium, Leuven and the European Comission's PASSYS Program. In its time, the project was on the cutting edge in the area of experimental work in building physics in the world.

The facilities were financed by the Chilean Ministry of Education as part of an academic innovation program that is explained in 6.3.3. They were conceived to improve the process of academic training and research in the area of building physics. Their use has enabled the development of research programs in the areas of water and thermal design of construction materials and elements in buildings, which are currently matters of high technical, social and political interest in Chile.

6.3.2. Law on construction quality and thermal regulations

On December 16, 1996, the Law on Construction Quality came into force in Chile. This law modified 18 articles of the Decree with Force of Law (DFL) Number 458 of 1975, the General Law on Urban Planning and Constructions. The law was conceived "to give a modernizing impulse to the activity of construction and, above all, to protect the safety and assets of those who acquire dwellings." It originated in numerous conflicts derived from building quality problems, often reported via social media.

The basic criterion that supports the Law is that each agent that intervenes in construction should be held responsible for his/her actions. Thus, on one hand, it precisely defines those to blame in the case of eventual damages or damages caused by flaws or defects in a construction; and on the other hand, it transfers from the Management of Municipal Works to private agents, a substantial part of the responsibility for the correct implementation of the General Law on Urban Planning and Constructions, in the works that these project or build.

In this way, those who buy dwellings know who to sue to assert their rights in the case that defects are detected in the building. The party responsible to the buyer will be the owner that first sells the property, even thought the

origin of the defect may be design errors, faulty construction or poor quality materials.

The owner that first sells the property, be they a real estate agent or a public agency like SERVIU, will be the entity first responsible for the damages caused by defects in the construction. They should ensure the proper performance of the professional draftsmen and builders, and will be able to repeat the lawsuit against them. Likewise, the builder should ensure the quality of the materials used in construction, for which he or she will be responsible, notwithstanding their ability to sue the manufacturer. This sequence of responsibilities, each of which is clearly defined, aims to guarantee that all those that intervene in construction commit themselves to the good building quality.

The implementation of this Law in 1996, highlighted a fundamental problem in the construction industry, a structural weakness: the country did not have sufficient laboratory infrastructure or specialized professionals in the area, with the necessary technological and analytic capacity to carry out diagnostics of flaws from hygrothermal problems. In practice, there was a lack of experimental and analytic tools to establish the causes of flaws and, as a consequence of said analysis, those responsible for them.

These are particularly complex matters in this area, in which for example, the causes of condensation could be design flaws, construction processes, materials, or misuse. Simple visual analysis is not enough; in many cases laboratory support is required to measure physical properties and to evaluate technical performance, and carry out environmental monitoring, etc., in order to establish causes and responsibilities. That support was not available.

The Law brought about the study of numerous testing and requirement regulations, and the installation of analysis techniques in some research and technological transfer centers. The effort was not enough, not yet even today, to meet the demands for laboratory services across the country. This "bottleneck" has always limited the process of updating and creating new regulations and research and technological development activity.[24]



Figure 6.2: Evidence of typical dwelling flaws in Chile. Source: CITEC UBB

In 1994, the Ministry of Housing and Urban Planning initiated studies to incorporate thermal insulation requirements into residential construction in Chile. The regulations, in their first stage, took effect in May 2000 and posed the same problem of lack of capacity in the country. The regulations obligated the certification, through testing, of the conductivity of materials and the thermal transmittance of roofs and walls after 2007. At that time, only two laboratories had installed capacities to provide those services

[24] In 2004, the Chilean Construction Institute convened the main technological centers in Chile to carry out INNOVA CHILE project Number C9CT-03: "Development of methodologies to prevent the occurrence of pathologies in social housing." It intended to resolve problems with lack of methods and tools of analysis to reduce the impact that flaw-related problems were having on the industry. It was CITEC UBB's task to develop a method to determine the acceptable standards of air permeability, watertightness and wind resistance of windows, considering geographical location in Chile (climate variables in the national territory) and the window's exposure situation. The method includes the verification of required standards through laboratory tests of life-sized window samples (NCh890, NCh891, NCh892). The method is required of all windows in dwellings with financing from the state in the Bío-Bío region since 2006; it is applied using the laboratories that CITEC UBB has in that region. Its application has been assessed very positively, but it has been impossible to extend to other regions of the country due to lack of installed laboratory capacity in other regions. A method with similar characteristics was developed to establish desirable classes of wall watertightness and to control compliance on site, which currently has the same impediments.

demanded by the industry and the Ministry of Housing: IDIEM, located in country's capital and CITEC UBB, 500 km to the south (currently there are three). The country extends 2,000 km to the north and south of both centers, which in addition to the low installed capacity to provide laboratory support for the regulations, leads to logistical difficulties in the transfer and mobilization of samples that make the problem more difficult.

In 2010, DICTUC succeeded in opening a laboratory for the thermal testing of materials. Another center, DECON UC, has made important investments to create similar facilities, but without success.

6.3.3. Mecesup Academic Innovation Project

The Mecesup-ubb 0001 project was carried out by the University of the Bío-Bío between 2001 and 2004. It is an academic innovation project financed by the Chilean Ministry of Education for the purpose of "improving and innovating in the teaching and research services provided by the Faculty of Architecture at the University of the Bío-Bío." The project proposed to improve the competencies and learning of and creation of abilities in students in the Faculty, so as to make the training process more practical for the interests and demands of society.

This project included, among others actions, the modernization of existing laboratories and the creation of new units for experimental work in building physics that were conceived and designed to meet local needs for research and training in the discipline[25].

[25] In 2002, in the framework of this agreement, this author carried out a master's degree program. The thesis was about the "development of test modules for experimental work in physics applied to buildings in Chile." In said work, the technical information necessary to design, implement and operate test modules or

The project's problem statement derived from a diagnostic carried out by the Royal Institute of British Architects (RIBA) in 1998[26], a diagnostic fully shared by academics in the Faculty of Architecture and authorities at that time. The report concluded that: "the majority of flaw-related problems in buildings in Chile derive from professional training, which fails to adequately integrate aspects of design with aspects of technology" (RIBA, 1998).

The consequences of the weaknesses detected at that time by the RIBA commission had important social and economic connotations. Quality problems and flaws in buildings; serious deterioration of habitability; inadequate behavior of buildings, materials and elements that do not comply with specifications, and other problems frequently reported through social mass media, objectively, could be explained by weaknesses in professional training. Keeping in mind this diagnosis, the project aimed to produce a change in the manner of teaching critical content in the Faculty of Architecture's plans of study, in those areas that were thought to be more fundamental to the the formation of graduate competencies in students. This included the area of building physics, among others.

"Test Cells" was developed for the experimental analysis of transport phenomena (HAM Transport) in life-sized construction element prototypes under real climate conditions. These units are currently available at CITEC UBB and are the first and only of their kind in Chile today.

[26] The Royal Institute of British Architects is the institution that has acted as the examining entity for the Faculty of Architecture since the 1990s. The diagnostic report issued by the examining board in 1998 recommended that academic training in architecture should be oriented toward the "acquisition of the technical capabilities that enable the conception of buildings that comply with the requirements of the users, respecting the limits imposed by factors and regulations regarding construction." Research activity was esteemed to be basic and incipient by the international board of specialists, and the laboratory infrastructure to support research processes and the training of human resources was neither sufficient for nor adjusted to needs. The board recommended the development of a curricular innovation project that served as the base to draw up the Mecesup-UBB 0001 Project.

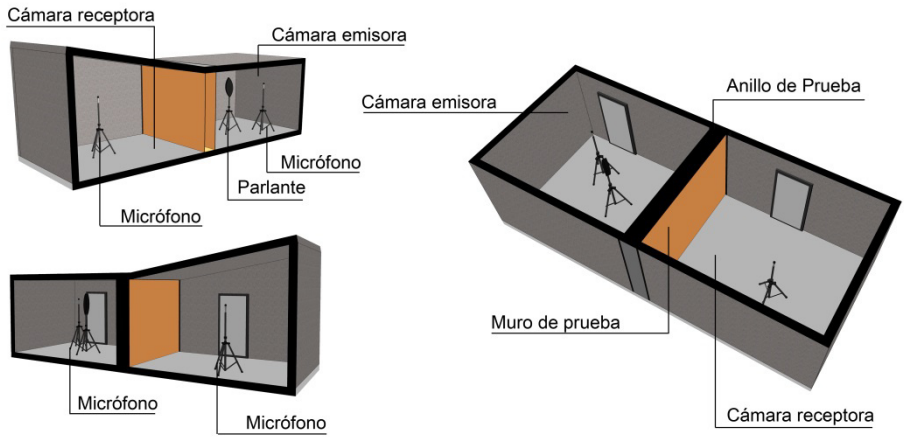


Figure 6.3: reverberation chambers, acoustics laboratory CITEC UBB. Source: CITEC UBB

The facilities in the area of acoustics consist of two reverberation chambers adjacent to one another, the first 50 m³ and the second 56 m³, designed according to the standard ISO 140-1 (NCh 2864), to obtain the airborne sound insulation properties of life-sized construction elements; equipment to determine the airborne sound insulation properties and impact sound insulation of elements in situ; and different computer tools for simulation activities, such as INSUL v6.2., SONarchitect ISO v2.2.15, and ZORBA v2.8 among others. With this infrastructure it is possible to carry out all the acoustic characterization work that the OGUC requires in article 4.1.6, as well as requirements under study and in the process of being incorporated as new requirements.



Figure 6.4: Determination of acoustic properties of dividing walls in dwellings. Source CITEC UBB.

Additionally, the Mecesup-ubb 0001 project enabled the implementation at CITEC UBB of the MPHT and MPST tests modules for building physics activities, which is explained in sections 6.4.2 and 6.4.3, and the facilities and techniques for testing and studies in the area of acoustics.

In the end, the project included the redesign and adaptation of the educational curriculum that area. The innovation took into account the use of physical simulation models (laboratories), as well as computer models (software and multimedia programs) and active teaching methods with support from these resources for learning essential content.

6.3.4. Innova Chile technological infrastructure project 05PFC01X-56

In 2007, this project was awarded to the CITEC UBB group in a contest organized by the Chilean state and was a central part of the government policies at the time to encourage applied research in Chile[27].

The project brought about a more than $4 million USD investment in new and improved technological infrastructure, which was added to CITEC UBB's existing infrastructure at that time. All together, at the University of

[27] The objective of the contest was to create and/or to strengthen research centers that support different areas of national industry. Support was given to 28 initiatives intended to meet the needs of different areas of national industry. CITEC UBB was awarded the project to support the construction industry. The unit's existing infrastructure and its curriculum in research and technological transfer were kept in mind at the time. The project, led by this author, proposed the creation of a Center for Research in Science and Construction Technologies at the University of the Bío-Bío. This development and technological transfer unit was proposed with the mission of developing, applying and transferring knowledge and technology developed at the University of the Bío-Bío to the industry and general Chilean community, in this way responding to their demands for research, innovation, specialized consultancy and human resources training.

the Bío-Bío it was possible to create the most complete infrastructure in the country to support the development of the construction industry in the center's areas of work, including building physics and sustainable architecture and construction. With the adjudication of this project, the institution also reached an agreement with Innova Chile on the creation of a unit intended to manage those capacities and assure the occurrence of the strengthening impacts promised by the project to support the national construction industry.

As a product of this project, the following were created: a laboratory for the post occupation environmental evaluation of buildings; a laboratory for the environmental and energy simulation of buildings, with tools such as TAS, Energy Plus, and WUFI among others; and a laboratory for structural and mechanical tests on life-sized construction elements. Diverse techniques were installed to carry out environmental monitoring processes for temperature, humidity, air quality, lighting, noise level and techniques for physical-structural decisions in situ, such as thermal transmittance and resistance, thermography, pressurization, tracer gases, and facade watertightness, among others.

The structures laboratory, which is prepared to carry out real-scale tests, was justified by the need to validate new construction systems. The Center's main research focus is concentrated on the new systems with improved environmental and energy attributes, which also need to show high structural performances to obtain authorization for use in Chile, as explained in 4.5.



Figure 6.5: Images that illustrate different decisions and processes monitoring physical building properties of dwellings in Concepción, Chile. Source: CITEC UBB

In addition, the project provided for the construction of a laboratory building that could serve a double purpose: to house part of the technological equipment and the Center's administration, and at the same time serve as an exemplary laboratory in sustainability and energy efficiency matters, topics that are important areas of work for the unit.

With those purposes, the building's design, its materiality, facilities and control system incorporated a series of strategies conducive to reducing the building's demand for and consumption of energy, improving environmental conditions and diminishing the impact on the environment. Active, passive and hybrid design strategies and innovative construction technologies and facilities, some of which are being used for the first time in Chile, are permanently monitored and evaluated at the CITEC currently.

The main strategies and technologies incorporated into CITEC's corporate building include the following:

The building was built of hollow, heat resistant, concrete blocks. The block and the construction system used are products resulting from Innova Bío-Bío Project Number 06-PC-51-004, carried out by center researchers and a group of Chilean businesses, between 2007 and 2008. This research and development project gave rise to this technology, duly tested and certified it

through the same project, and used it for the first time in Chile in this building.

The thermal resistance of the new block used in the building duplicates that of traditional blocks, and adds water resistant properties that make it appropriate for use in rainy climates. The perimeter walls were formed based on these blocks plus an interior thermal cladding, in this way obtaining a highly energy efficient thermal envelope. The certified thermal transmittance of the building's perimeter walls is less than 0.5 W/m 2°C. The thermal losses through an envelope with this standard are respectively, four and eight times less than those produced by typical brick masonry and concrete wall envelopes in Chile. It incorporates transparent, double-paned window elements and curtain walls, and roofs and floors with certified hygrothermal quality standards.

The airtightness of the envelope reaches 8 1/h air changes per hour, not the best standard; however, it can be compared with that of comparable constructions presently in Chile, which have double the amount. The building incorporates Trombe walls and movable louvers in its main facade, and an intelligent control unit based on PLC (Programmable Logical Controller) to achieve optimum thermal use of the systems and the building.

At the facilities level, the building incorporates various systems to meet heating, cooling and ventilation demands during the year. These are independent systems based on building sector or area. Their purpose is also pedagogical; the facilities design incorporates systems to count and monitor energy consumption and environmental variables. Among the most important that stand out are: The geothermal heat pump and radiant floor coil systems, for heating and cooling the building during the different seasons of the year and as needed; the solar heating system based on solar

panels, to provide hot sanitary water and to support the heating of the building; the condensation boiler system, to provide heating through a high energy efficiency, gas-powered condensation boiler, and radiant floor coils; and the hybrid ventilation system made up of a ventilation chimney, ventilating devices for walls and penetrations, hybrid extractors with the possibility for natural and forced ventilation, and CO_2 concentration and environmental temperature sensors.

At the same time, the building has an intelligent centralized control system that is responsible for monitoring and registering energy consumption, and tracking and controlling environmental variables by building zone. The system is made up of a central programmable logical controller; sensors and actuators deployed in different sectors of the building and outside; a central control computer; and an interactive screen with on-line information on all the building's variables of interest, such as: energy consumption, exterior temperature, indoor temperature, temperature between wall and roof layers, humidity, CO_2, damper state, etc. It is possible to monitor this information on line through a main screen that is available for those effects or via the Web, through a system developed for this purpose by CITEC researchers.

All the building projects were developed by researchers from the CITEC group. The measured energy demand for the thermal-environmental conditioning of the building is of 18 kWh/m² per year. This indicator is evidence of a very high energy efficiency building (in Chile). Comparable ordinary buildings in the city of Concepción have energy demands between 80 and 180 kWh/m^2 per year.



Figure 6.6: CITEC UBB corporate building. In the foreground, the Trombe wall system .



Figure 6.7: Plan of the hybrid ventilation system in the CITEC UBB corporate building.

6.3.5. INeS Project

Mineduc Project 1205: "Innovation based on biomaterials science and energy efficiency for a sustainable habitat," awarded to the University of the Bío-Bío in 2013, to be carried out during the 2013-2016 period [28]. The

[28] Administered by the Ministry of Education, this fund finances Performance Agreements for Innovation based on science carried out by higher education institutions. The first official contest in 2012 possessed $15 million USD in funds to be distributed to three institutions. The agreement seeks significant institutional improvement to increase innovation based on sciences in Chilean universities and

proposed objective of this project is to increase the innovation activity based on science at the University of the Bío-Bío, to achieve international competitiveness in the field of Biomaterials and Energy Efficiency for a Sustainable Habitat.

This project represents the largest investment made in the area of sustainable construction in Chile. It will enable the development of an R&D program aimed at obtaining a set of technological packages of great importance for the development of the sustainable construction industry in Chile, along with financing infrastructure and the training of human resources for the development of such packages. Notable indicators of the project are: the number of patents, the number of technological transfer services, the quantity of economic resources obtained, the number of participating researchers and students, the businesses created, etc[29].

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for them to achieve international competitiveness in the fields in which this is feasible.

It requires that universities identify and apply in their strongest areas, which are those with greater demonstrable work in technological innovation. The University of the Bío-Bío applied in the area of habitat and sustainable construction and was one of the three selected. The initiative presented is called "Exploitation of world-class knowledge and innovation in biomaterials and energy efficiency for a sustainable habitat." In this initiative, a model of strategic alliances with national and international institutions and businesses is set out in order to form a consortium that tackles the demands for innovation, development and transfer in the field of Sustainable Habitat, which is understood to be a world issue. It is separated into three areas of development: Biomaterials, Cities and Sustainable Construction, the last of which is led by the author of this thesis. The agreement commits to a series of results; the main one is the development and placement of at least 30 technological packages on the market.

The awarding of this project to the University of the Bío-Bío recognizes its work carried out in sustainable construction in the last 20 years and establishes this university as the main development center in the field in Chile.

[29] The strategic development plan created in this thesis will serve to identify and prioritize initiatives to carry out in this MINEDUC Performance Agreement. The plan defines the action program recommended to improve the environmental and

The project will enable the assembly of: a modern laboratory to address issues in ventilation and air quality and an advanced laboratory for the physical simulation of building models exposed to artificial climate conditions, as well as workshops and greater spaces for the production of prototypes and other things, equipment to provide the laboratory services that the R&D activity to be carried out in the coming years will demand, and the support activity for the installation of the new regulations that Chile needs.

6.4. Major Equipment and Main Installed Techniques

The main experimental facilities and techniques installed in laboratories in Chile in the area of building physics are described here; these are of normal or habitual use in development activities and in hygrothermal and energy studies of buildings. The following stand out:

6.4.1. Thermal testing module (Hot Box)

This module is used to determine the steady state thermal coefficients, such as U factor, h factor, C factor, of non-homogeneous wall panels, roofs and floors in buildings. It uses life-sized samples and tests are carried out under controlled laboratory conditions. It uses the standard hot box apparatus method, which is recognized as an absolute method by ASTM and ISO. It is used in the certification of construction element properties and product development. Testing and construction of the equipment is governed by NCh 851 Of 2012: Thermal insulation - Determination of steady state thermal transmittance properties and related properties - Calibrated guarded hot box.

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energy quality of housing construction in Chile; strategic axes, courses of action and projects to develop in the next 10 years to meet that objective are indicated.

This a translation of the ISO 8990:1994 standard. In Chile the technique is installed in IDIEM, DICTUC and CITEC UBB.

A diagram of the apparatus is shown in Figure 6.8. It consists of three chambers, or boxes, open on one of their sides: a guarded or hot chamber (a), another cold chamber (b) where cold and hot environments are simulated, respectively; and a measurement chamber (c), located in the hot chamber's interior, positioned symmetrically with respect to its container. The life-sized sample is placed between the cold and hot chambers, separating both environments.

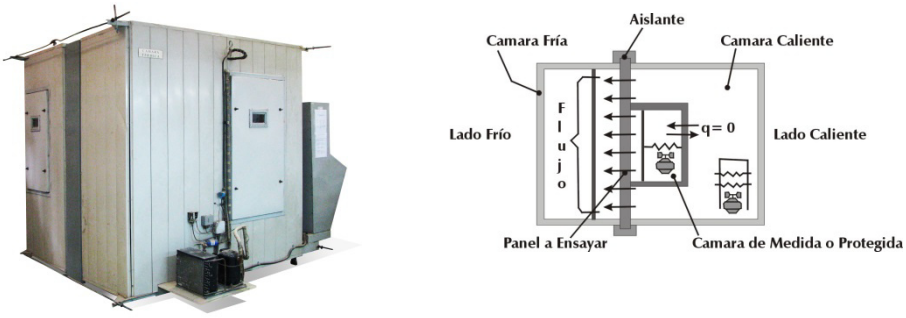


Figure 6.8: Image and diagram of thermal tests at the CITEC UBB Construction Physics Laboratory. Source: CITEC UBB

The method is reduced to knowing the heat flow that crosses the construction element and the temperatures that propel it, under steady state conditions. The flow is electrically produced and determined in the measurement chamber and crosses a measured section of the sample, which separates a heated enclosure and a refrigerated enclosure. In this way, a quantity of heat flows through the construction element that is inversely proportional to its thermal insulation.

During the test, an attempt is made to maintain the same temperature in the hot chamber and in the measurement chamber, to minimize the exchange of lateral heat and produce what is known as the adiabatic effect or null flow. In the ideal situation of zero lateral heat exchange, the heat generated inside the measurement chamber passes entirely through the sample. Thus, by measuring the heat dissipated in its interior, an indirect measure is obtained of the heat flow that escapes through its mouth and crosses the construction element.

In practice, it is not always possible to achieve the ideal condition of null temperature difference between the measurement and hot chambers. For this reason, it is necessary to set up the walls of the measurement chamber as a flow meter. To this end, differential thermocouples connected in series, two by two, are used and installed in the center of each wall opposite one another. Thus, a thermoelectric battery is created that enables the measurement of the temperature difference between the interior and exterior surfaces of the measurement chamber wall. Given that all the thermocouples are connected in series, their thermal electromotive force is combined.

In this way, knowing the tension generated by the thermopile in relation to the flow that crosses the chamber walls, it is possible to know the flow that is added or subtracted from the main flow. To determine the relation between the flow that crosses the measurement chamber walls and the electromotive force from the thermopile, the flow meter is calibrated previously to determine its coefficient of proportionality. The operation of this flow meter is fundamental to the quality of the results that the method produces.

Proper design and execution of the thermopile is important, as well as correct laboratory practices. The reliability of the results depends essentially

on this. Its main drawback is that the method is not applicable with damp materials, a condition in which they are found in reality. The necessity to maintain the steady state conditions required for the test modifies the moisture content of the materials.

The technique is of low complexity; the test lasts between 3 and 7 days depending on the mass and moisture content of the walls. The approximate cost of the test is $500 USD.

6.4.2. Solar Thermal Test Module (MPST)

This module is used to experimentally determine the heat transfer coefficient, UA-factor and the solar transmittance coefficient gA-factor, of life-sized passive solar components under real climate conditions. It does not use a standard method, but rather one universally assumed to be valid: the PASSYS Test Cell method, originally proposed by Baker in 1983 in a project for the European Commission (E.C., 1994).

The project was carried out between 1986 and 1996 in several phases, and included the participation of laboratories from 10 countries in the European Union. At that time, Baker proposed the construction and installation of 35 highly standardized Test Cells for the outdoor study of passive solar components (Linden, V et al, 1995). Through this work, a complete catalog of the thermal and solar properties of passive solar component designs was created and information was developed on Test Cell operation and execution techniques. The experience and knowledge developed in this project was used to build a module with similar characteristics at CITEC UBB in 2005 (Bobadilla A., 2002).

The module built in Chile consists of two, well- thermally-insulated rooms, with a heating and cooling system and systems to measure and control variables, exposed to real outdoor climate conditions. The layout is based on Baker's original design carried out at the DFVLR in Stuttgart. The bigger room, called the Test Room, is basically a calorimeter with the equipment necessary to make precise measurements of heat exchange between its interior environment and the exterior. The element being tested makes up one of the sides of this room. The smaller room, called the Service Room, contains the main control and measurement equipment.

The Test Cell is available at CITEC UBB. Its structure is made of wood elements and panels and it has a floor area of 2.75 x 5.0 m^2 with an internal volume of 38 m^3. Its main characteristic is the high level of insulation ($U \leq 0.15$ W/m² K) in its envelope, and also high airtightness (N50 < 0.1 1/h). The heating and cooling system consists of three units: an air distribution unit with an adjustable volume fan; a double loop cold unit, with a conventional cold machine; and a reservoir of cold water and heating with the corresponding control devices.

Figure 6.9 shows general characteristics of the PASSYS Test Cell. Figure 6.10 illustrates the variables that intervene in the energy balance and PASSYS Test Cell method.

The method comes down to knowing the net flow that crosses the construction element and the thermal conditions of the environments between which it moves. The test element is placed in an opening in the wall of the test room, and is submitted to real exterior climate conditions on one side and to recreated conditions (the interior climate in the test room) on the another. The net flow is determined by knowing the difference between the

power of heating and/or cooling injected into the test room and the thermal gains or losses through the envelope of the same room.

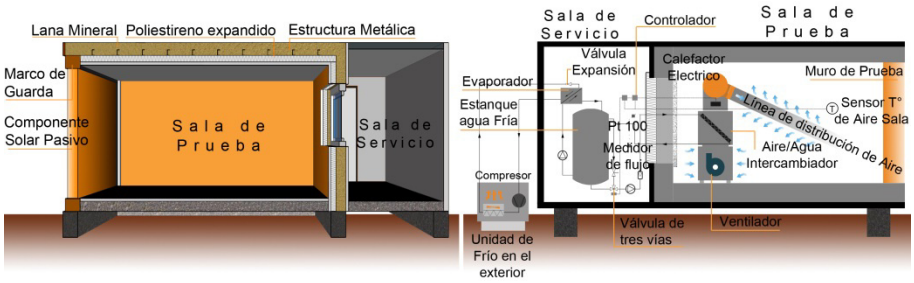


Figure 6.9: Characteristics and diagram of the Test Cell's heating and cooling system at the Construction Physics Laboratory, CITEC UBB. Source: CITEC UBB

The main steady state properties that are sought are the coefficient of heat loss due to transmittance (UA) and the solar transmittance coefficient (gA). Both characteristics cannot be measured directly. For this reason they must be deduced from the thermal balance of the Test Cell. In practice, the quantity of heat contributed to or extracted from the Test Cell to maintain a determined interior temperature condition is measured. This quantity is in direct relation to the solar and thermal characteristics of the construction element submitted to testing and the Test Cell, which are known.

For a steady state situation, the thermal balance equation of the Test Cell has the following terms:

1. Heat losses or gains in the test room through the construction element (unknown).
2. Power of heating injected into the test room (measured).
3. Power of cooling extracted from the test room (measured).
4. Heat losses in the test room through its envelope.

The heat losses through the envelope are calculated knowing the temperature difference between the surfaces of the elements that make up the exterior envelope of the test room and their corresponding values (UA). The values (UA) are determined through a prior test calibration of the test room and are characteristic of each Test Cell.

The Test Cell balance equation and the detail of the techniques that apply to the processing and analysis of the information in order to obtain the coefficients are explained in detail in (Bobadilla A., 2002). The key to the method is the precise measurement of the heat flows involved, and the appropriate regulation and control of the heating and cooling systems to maintain the system in balance. The period under consideration is another important aspect; experience shows that it is necessary to integrate values for long time periods to correctly determine the steady state equation.

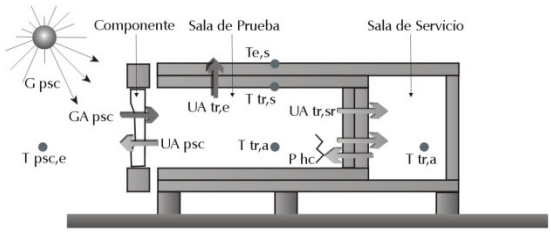


Figure 6.10: Diagram of flows that intervene in the balance of the Test Cell according to the PASSYS Method. Source: The PASSYS Service European Commission

The method is relatively complex and requires moderately difficult measurement techniques. The main disadvantage is that it does not deliver information on the dynamic characteristics of the component related to its accumulation capacity; the duration of the test is long; and also, the method ignores the possible effects of short-term climatic changes resulting from

variations in cloud cover, external temperature or the position of the sun. A minimum period of 20 days is needed per test.

Short periods, a day for example, present the problem that the average heat losses through the component are influenced by the previous day's climate. This fact is ignored in steady state analysis, which integrates various periods or cycles and in this way tends to minimize the effects of inertia. In this way, the effect of heat accumulation has a greater impact on the contamination of the analysis when climatic oscillation is higher: a day with relatively high heat losses preceded a day with lower heat losses. The influence of the previous day "drags" the value of the highest losses downward.

To overcome these difficulties, improve precision and reduce testing time, it is necessary to use a dynamic state PASSYS method. This method was also developed by the PASSYS team and is applicable to the thermal analysis of passive solar components under dynamic conditions. The method is based on experimental measurements and the use of a transient mathematical model of the Test Cell-component system that must be developed previously. This work has not yet been carried out in Chile.

6.4.3. Hygrothermal Test Module

Although not standard, this method is universally assumed to be valid. It was developed through the VLIET Test Building project at the Bouwfysica Van de K.U. Laboratorium. (Janssens, A. & H. Hens 2000). It is used to study transport phenomena under real climate conditions; obtain characteristic coefficients such as U-factor and h-factor; and determine heat, air and moisture flows through life-sized component samples of walls, roofs and floors.

The VLIEST Test Building Project is an initiative that was proposed by the Construction Physics Laboratory, K.U. Leuven to create an experimental facility that could be used for the following purposes: to obtain a better perception of the "HAM-effect" and its influence on the global physical behavior of envelopes; to understand the influence of each layer of material on the hygrothermal quality of envelope components and entire buildings; and to contribute to the development of durable and energy efficient envelopes. To accomplish the purposes indicated, an experimental facility was designed and built to study envelope components exposed to real climate conditions and evaluate their energy efficiency, hygrothermal behavior and durability.

In Chile, this experience was used as a reference to design, build and operate a facility of similar characteristics at CITEC UBB. It is referred to as a hygrothermal test module (MPHT) and has been in operation since 2006 (Bobadilla A., 2002). The MPHT module is a physical simulation model, a 59.6 m^2 construction that simulates the hygrothermal behavior of a building. The building envelope is made up of the test elements, walls, floors and roofs, that can feasibly be removed and interchanged.

The module accommodates 6 wall elements, 5 roof elements and 3 floor elements. The wall and roof elements are repeated twice and are located in the position in which they function: half of them oriented to the north and the other half to the south. The module is capable of receiving 25 samples, which result in an equal number of workstations. The double arrangement of wall and roof elements enables the element's behavior to be observed in all directions. Northern exposure in Concepción is sunny, but strongly affected by driven rain in winter; on the contrary, southern exposure receives a smaller proportion of solar radiation and less intense winds, but is more humid.

The samples are of a "representative size," so that the exposure conditions and then the results obtained in the test module can be integrated into the results of in-situ evaluations in occupied buildings. A system of air conditioning sets and controls the interior climate conditions for operations during all the seasons of the year. Occupation conditions are simulated through programmed heat and moisture loads. Exterior climate conditions are monitored with a weather station that continuously collects all the variables of interest. The module includes the equipment and monitoring, control, processing and data analysis systems that the different techniques and test methods require.

The equipment includes different instruments and sensors to measure characteristics of the elements under study and the environment. The techniques have been installed over the years to monitor and measure real-time heat flows, condensation occurrence, moisture content in different types of materials, and air quality and flows, among others. The experimental techniques are combined with models and algorithms for transient state evaluations.

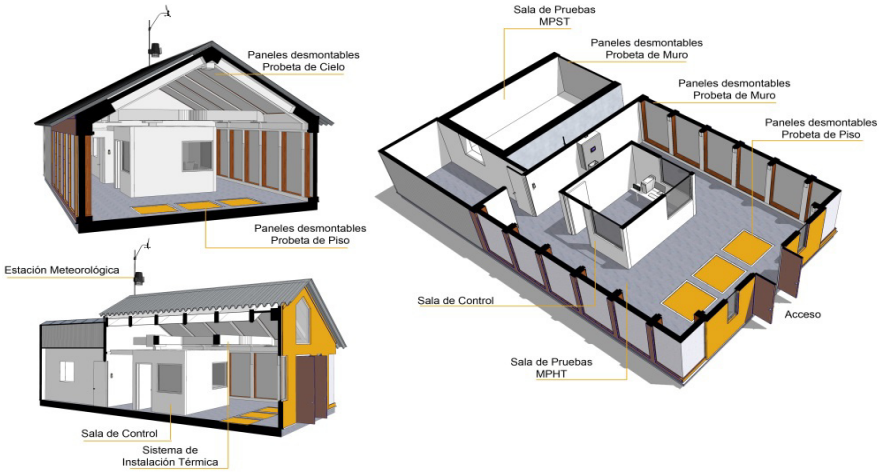


Figure 6.11: Diagram of interior MPHT distribution at CITEC UBB. Source: CITEC UBB.

The MPHT and MPST modules were also designed to help in the teaching of building physics in Chile. The facilities are contributing to the development of new ways of teaching this discipline in the country. They incorporate the use of multimedia and teaching software, to develop visual proof of physical phenomena associated with the real operation of buildings. These phenomena have complex theoretical explanations and therefore tend not to be understood well.

The MPHT and MPST modules are the main available units in the country for experimental activity in building physics. At the time, they were conceived to achieve the best balance between local information needs (Chile), costs and time involved in thermal, water, and solar tests of life-sized building components under real climate conditions.



Figure 6.12: Images that illustrate different determinations and diagram of the tracking and control of variables in the Hygrothermal Test Module. Source: CITEC UBB.

6.4.4. Other equipment and techniques

Interest in improving the efficiency of energy consumption in the building sector caused the need to measure environmental and energy performances. Measuring quantified impacts and evaluated the profitability of the actions

that were being implemented in buildings to improve their energy quality. Toward the end of the previous decade, it arose as a need to support the energy audit programs promoted by the national energy efficiency program, which was the predecessor of the current Chilean Energy Efficiency Agency.

For these purposes, a series of well-known monitoring techniques was implemented based on the use of sensory networks and devices to capture, transmit, process and control, in real-time, data applicable to the measurement and control of the energy consumption and environmental variables of buildings and dwellings. Additionally, a series of techniques were implemented to measure important physical-structural characteristics of buildings in use, among which the following stand out: techniques based on thermography and heat flow measurement to measure envelope insulation; tracer gas techniques to evaluate ventilation; and techniques to monitor indoor climate variables associated with the hygrothermal, acoustic and light behavior of buildings.



Figure 6.13: Images that illustrate different determinations and the monitoring of physical properties in dwellings in the city of Concepción, Chile. Source: CITEC UBB

Through the monitoring process, it was attempted to exploit the building to objectively measure performances, using techniques frequently used in developed countries to evaluate a building's design and construction process, the consuming facilities and the form of use.

At an international level, monitoring techniques became important at the beginning of the 1990s, first as tools to calibrate and validate computer models of energy and environmental building simulation, and later as powerful tools for the energy management of buildings as well. This is currently considered as an active element in a strategic methodology for the improvement of a building's energy and environmental services, throughout its life cycle: from the design, to prevent behavior, to the building exploitation phase, helping to control demand, reduce energy consumption and improve habitability conditions (IEA, 2005).

A milestone in the installation of capacities to monitor buildings in Chile is the Innova Chile Project Number 09 CN14-5706: "Evaluation of Construction Design Strategies and Standards of Environmental Quality and Use of Energy in Public Buildings, by means of Monitoring of Constructed Buildings," which was executed between 2010 and 2012[30]. This project provided for the design and implementation of monitoring protocols to measure building and facilities performances, along with a method to rate performances and make judgments on the quality of the passive and active design strategies incorporated in buildings. This "benchmarking" method,

[30] This project was coordinated by the Construction Institute and executed by a technological consortium consisting of the main technological centers in the area in Chile. Directed technically by this author, the project enabled the development of technological know-how to monitor buildings and objectively measure their environmental and energy performances, and to support design processes that optimize the energy and environmental aspects of public buildings in Chile. The project involved the monitoring of 10 public buildings in five regions of the country. Its objective was to evaluate design, indoor environment, installations and user perceptions, and quantify building performances in a way that had not yet been done at that time in Chile. The work was mandated by the MOP's Architecture Directorate, with the purpose of evaluating the great investment the Chilean state was making in the environmental and energy improvement of public buildings. The study involved the evaluation of buildings created with and without energy efficiency criteria within the same region. Additionally, it was intended to identify and develop energy saving opportunities applicable to the design and construction of future public buildings.

compares measured performances with references of good, acceptable, and bad performances (Bobadilla et al, 2012). Through this project, the efficacy of the design strategies used in different thermal zones in Chile was evaluated, and once and for all, what was being done well was made known. Proposals for energy savings and the improvement of the environmental quality of public buildings were identified and developed. This information was summarized in a Technical Manual that is regularly used in Chile (I. C., 2012).

In Chile, monitoring techniques are still in an exploratory phase. They are installed in no more than two centers and it is estimated that their widespread use for design and energy optimization purposes will occur in the medium-term future.



Figure 6.14: Visualization of environmental variables, CITEC UBB building. Source: CITEC UBB

6.5. Conclusions and Comments

From the review of the laboratory infrastructure in building physics, its process of creation and the comparison with current and future needs for laboratory activity, the following is concluded:

The building physics laboratories in Chile were created to meet technical and social needs that emerged strongly in the last two decades in the country.

These include needs from the Construction Quality Law of 1996: to provide experimental scientific support to studies of construction pathologies and establish causes and those responsible for them; support needs for the installation of the thermal regulations of 2000 and complementary technical regulations; and needs to support processes of development and/or adaptation of new materials, elements and construction systems that were motivated by the thermal regulations.

95% of the installed capacity is concentrated in only four laboratories and approximately 80% in only two laboratories: CITEC UBB and IDIEM. The level of the facilities in these two centers can be compared with that of existing international facilities. Also, it is adapted to the requirements of the majority of the R&D and testing activities to support the regulations that the country should create in the next 10 years. Nevertheless, the country's capacity is insufficient to address the entire volume of work currently required and the work that is projected for the next 10 years.

The equipment and required testing techniques to support the application of regulations and carry out research are nearly all installed, but in very few laboratories. Most of them are only present in a single laboratory and others in no more than three: thermal evaluations in two laboratories, airtightness evaluations in three laboratories, and hygrothermal evaluations of life-sized elements in one laboratory. Additionally, it is necessary to improve the capacity to carry out tests and verifications of building airtightness, air quality and indoor climate variables in general (acoustics, heat, light), facade watertightness, and thermal and water properties of materials and elements in situ.

There are basically two main challenges: to support the process of putting new testing regulations and requirements into effect throughout the country,

and to support the development of new material technologies and construction systems in the next 10 years. On this matter:

In order to provide support, it is necessary to install at least one reference laboratory per region (15) with the installed capacity to meet, from within the region, the demands for verification of conformity of construction projects and businesses in each of these territories. Continental Chile stretches for more than 4,200 km and considering the existing centers, it is necessary to install and/or reinforce capacities to create at least 15 new centers.

To support and develop R&D activities, it is necessary to strengthen the research work in the existing centers. This will occur by training and integrating new researchers into the field and installing new experimental facilities. Currently, there are not more than 20 researchers with doctoral degrees working in the area. In the next 4 years, at least 6 new doctoral professionals will begin to work in the field and at least 10 more are required to tackle the research that is deemed necessary for the next 10 years. This work is defined in chapter 7.

Nowadays, the work of incorporating new regulations and standards into the OGUC and development research in Chile are seriously limited due to the lack of technological infrastructure. This is a critical weakness at this time that the development plan should consider.

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7.0. STRATEGIC DEVELOPMENT PLAN 2015-2025

This chapter presents a prioritized plan destined to improve the environmental and energy quality of housing in Chile within 10 years. This plan is structured on the basis of axes and strategic objectives, goals and measurable indicators, as well as a set of actions, programs and projects to achieve this social objective.

7.1. General background

The buildings sector is responsible for 26% of final energy use in Chile (MINVU, 2012). 44% of that energy is intended for heating residential buildings. These figures are excessively high considering the relatively benign climatic conditions in the territory where most of the country's population is concentrated. The problem is the low performance of energy use in the sector; the housing stock demands twice the necessary energy for its thermal conditioning, as shown by the diagnostic carried out.

In order to grow, the country needs greater amounts of energy and to disconnect its economic growth dynamic from that of energy consumption. Consequently, the challenge of Chile today is to possess sufficient, competitive energy resources and improve energy use performance in all sectors, particularly in the buildings sector, as it is the area with the greatest savings potential due to energy efficiency (AChEE, 2014).

A National Energy Strategy (MINERGÍA, 2012) and a National Sustainable Construction Strategy (MINVU, 2012) are in force in Chile. They define the major lines of action in the country. In addition, there are several institutions, centers and universities that specialize in the subject of housing quality in its different dimensions. Nevertheless, an instrument that guides and defines

goals and specific actions to improve the energy quality of housing from a country perspective is lacking. Like the one proposed, this plan must be supported with scientific evidence and integrate the sustainability and energy efficiency criteria from the national strategies, with the main purpose of reducing the quality gaps in the housing stock.

7.2. Methodological approach

Different techniques and methods were used in the Plan's construction, namely:

7.2.1. SWOT Strategic planning strategy

Normally, it is used in the area of business organizations. It is used to identify the condition of an organization, its strengths and weaknesses, and the opportunities and threats it faces, which are presented in a SWOT matrix, as shown in Figure 7.1. From this analysis, strategies are deduced that use the strengths to take advantage of opportunities and/or reduce threats and minimize the weaknesses to achieve the objectives sought.

This entire planning process is carried out following a Vision (what we want the housing stock to be in energy terms) with a Goal (a quantitative expression of this vision) and a Mission (what should be done to achieve the vision).

MATRIZ FODA	Fortalezas (F) 1. 2. 3. 4. 5.	Debilidades (D) 1. 2. 3. 4. 5.
Oportunidades (O) 1. 2. 3. 4. 5.	Estrategia (FO) 1. 2. Usar las fortalezas para aprovechar oportunidades 3. 4. 5.	Estrategia (DO) 1. 2. Minimizar debilidades aprovechando oportunidades 3. 4. 5.
Amenazas (A) 1. 2. 3. 4. 5.	Estrategia (FA) 1. 2. Usar fortalezas para evitar o reducir el impacto de las amenazas oportunidades 3. 4. 5.	Estrategia (DA) 1. 2. Minimizar las debilidades y evitar amenazas 3. 4. 5.

Figure 7.1: SWOT analysis matrix with feasible strategies.
Source: Fred R. David. (2000). Strategic Administration

The SWOT analysis technique was applied to the "Chile organization" as a country. The technical, economic, social, and political factors that account for the scenario that the "country organization" faces and serve as input and a foundation for the diagnostic, have been presented in the previous chapters.

7.2.3. Balanced Scorecard Methodology (BSC)

This management tool was developed by Kaplan and Norton to translate the strategies of a business organization into a series of coherent objectives, measurable indicators and actions (Kaplan, R. & Norton, D., 2007).

This technique is applied with the necessary adaptations, due to the importance that the measurement and monitoring in a Plan of this nature should have and under the premise of the technique's creators that what is not measured cannot be managed[31].

[31] The elaboration of the housing stock's energy quality baseline was also contemplated to establish a point of reference to measure the Plan's progress. With that objective, the Plan includes the (AL 06.3.1.2) line of action. Thus, it is considered necessary to evaluate the new constructions from the years 2020 and 2025, using the same methodology developed in this thesis.

This analysis begins with the definition of strategic axes that result from the SWOT matrix, and looks at the definition and development of the following areas:

Strategic objective, S.O.: It declares the scope and achievement desired with the development of each strategic axis.

Specific objectives: They define desired achievement in areas or more relevant lines of the strategic objective.

Indicator: It defines the criterion and the metrics to be used to monitor and measure progress and achievements in the specific objective.

Lines of action: It indicates the mechanism or activities to carry out to accomplish the specific objective, such as projects and programs, among others.

Lastly, all this information is summarized in a Strategic Objectives and Lines of Action matrix.

7.2.4. Strategic evaluation based on quantitative weighting

It is used to numerically value the importance of the different actions and prioritize the plan, considering the availability of resources and periods of time. It considers factors such as the country's economic and technological capacity, the existing quality gaps, the causes and relative degree to which they influence housing quality, social and cultural factors, and previously undertaken work and national and international practice in the area. This background is considered to define prioritized criteria, which are weighted and validated with the help of a panel of experts.

The criteria to prioritize and organize the execution of the Plan's projects and actions over time include the following:

Validity: The initiative or project helps to resolve a problem or recent need in the country (less than 5 years); a mid-term problem or need (between 5 and 15 years) and a long-term problem or need (more than 15 years).

Effect and cause: The initiative or project helps or takes care of a very important, important, or not so important cause that explains housing construction quality and needs in Chile today.

Economic and technical feasibility: The initiative or project is unlikely, feasible with moderate difficulty or feasible due to its costs or the physical infrastructure capacities or human resources that it demands.

User perception: The initiative or project helps to resolve a problem that the average dwelling user in Chile perceives as not so important, important or very important.

Perception of Authorities: The initiative or project helps to resolve a problem that specialists and authorities in Chile perceive as not so important, important or very important.

Relevance: The opportuneness of the initiative is low, average or high, considering the combination of: existing needs, advancements in the field, and national and international concerns about the matter.

Table 7.1 shows the criteria and the weight assigned to each in order to prioritize the projects and initiatives derived from the Development Plan.

The range of prioritization in this evaluation is 12 points: 18 points is the maximum level and 6 the minimum.

Table 7.1: Prioritization criteria for initiatives and projects in the Plan and their weighting

Criterios	Descripción	Ponderación
Vigencia:	Menos de 5 años	1
	Entre 5 y 15 años	2
	Más de 15 años	3
Efecto y causa:	No tan importante	1
	Importante	2
	Muy importante	3
Factibilidad técnica y económica	Poco factible	1
	Factible con dificultad moderada	2
	Factible	3
Percepción del usuario	Problema no tan importante	1
	Problema importante	2
	Problema muy importante	3
Percepción de las autoridades	Problema no tan importante	1
	Problema importante	2
	Problema muy importante	3
Pertinencia:	Baja	1
	Media	2
	Alta	3

Source: Created by the author.

7.2.5. Strategic evaluation based on qualitative weighting

It is used complementarily since the quantitative evaluation does not discriminate between the importance of one evaluation criterion or another.

The qualitative evaluation considers only two criteria with three levels: the drag criterion and the viability criterion. The levels are high, medium and low and it is also carried out with the help of a panel of experts. These criteria and levels define a strategic plan or map, where the initiatives are finally located to appreciate their importance and prioritize the plan.

The drag effect is understood as the capacity that the project has to generate synergies and trigger other initiatives that help and are necessary to improve

the energy quality of housing. Three levels of the drag effect are differentiated: low, medium and high.

Viability is understood as the possibility to bring the project to fruition. It is evaluated based on the following criteria: costs and availability of economic resources, available technological capacities, and the way in which it compares with the challenge or complexity of the initiative. 3 levels of viability are are differentiated: low, medium and high.

For the purpose of this evaluation, projects are classified into four types:

Preferential projects: These projects have a high drag effect on other actions as well as a high viability of execution.

Driving projects: These projects have a high drag effect, but are normally difficult to execute. They are the critical actions in the Plan.

Secondary projects: These projects are easy to execute, but have a low drag effect. They are used to complement or reinforce other actions.

Problematic projects: They have a low drag effect and are difficult to carry out. They can be omitted or postponed.

Considering the aforementioned factors, the strategic matrix shown in table 7.2 is constructed, which finally presents the initiatives.



Figure 7.2: Qualitative evaluation matrix of projects and initiatives. Source: Núñez F., op.cit.

To prioritize a project, the quantitative weighting is carried out first and the initiatives are ordered according to their importance, in accordance with that criterion. Subsequently, the second qualitative evaluation is carried out, in which projects are classified in four priority levels or ranges, as follows, for notation purposes:

Initiative A: Of first importance; Initiative B: Important; Initiative C: Less important.

7.2.6. Conceptual map of prioritization of lines of action

Finally, both conceptual approaches of evaluation are integrated in a Cartesian coordinate system, where the different lines of action of each strategic axis are located, as shown in figure 7.3. Map as a strategic planning instrument.



Figure 7.3: Map of qualitative and quantitative prioritization of the Plan's actions. Source: Created by the author.

7.3. SWOT analysis

The summarized list of the main weaknesses, strengths, opportunities and threats deduced from the internal and external analyses are:

7.3.1. Weaknesses:

1.- Inappropriate regulatory framework: The regulatory framework, made up of regulations, standards and accreditation systems is insufficient, obsolete and very basic. It does not help for the purposes of obtaining dwellings with socially acceptable energy quality. The obligatory requirement standards are low, there are unregulated areas and support for standards is minimal.

2.- Limited development research: There is a low volume of R&D work, which is moderately effective in terms of innovation. The research that results in products placed on the market is limited; the majority, more than

80%, does not progress past the pilot stage of technology testing and/or results in flawed products.

3.- Lack of culture of innovation: Chilean society and the industry are disinclined to innovation and to assuming its risks. This situation is reflected in the market: 80% of dwelling construction uses traditional construction systems and the majority of the new construction systems use materials on the market, which are foreign products introduced into the local market without any degree of adaptation to the country's climatic, technological or cultural conditions.

4.- Insufficient critical mass: The human resources available are not sufficient to carry out the necessary work to reduce the quality gaps by the deadlines set out in the Plan. Currently, the building stock demands twice the amount of energy that it should, and the number of researchers that work with Fondecyt, Fondef and Innova does not exceed 40, the majority which are only partially dedicated to this task. Also, more than 80% of them are concentrated in no more than three institutions in Chile.

5.- Limited funding: All the resources for the research on and installation of technological infrastructure are obtained through contests for competitive funds. Research investment in Chile is low; it does not exceed 0.4 % of the GDP and it is very low in the area of housing. The number of contests for funds has been low and not sufficiently competitive. Historically, investment in the area only reaches 0.38%; nevertheless, the housing sector contributes more than 5% to the national GDP.

6.- Limited laboratory infrastructure: The national capacity is insufficient to undertake the entire volume of present and future work during the next 10 years. There are basically two main challenges: to support the process of

putting into effect a quality accreditation system that covers the whole country and to serve in the development of new material and building system technologies. 95% of the laboratories are concentrated in only 4 centers, all of them located in the central zone, which generates service coverage problems, considering the country's length.

7.3.2. Strengths:

1. Political will and institutionality: There is an institutional and legal framework for the actions in the Plan. This includes the Chilean Energy Efficiency Agency, which is responsible for articulating actors and defining lines and priorities and is the first of its kind in Chile and Latin America. Recently, two national development strategies have been put into practice: The National Sustainable Construction Strategy 2012-2030 and the National Energy Strategy 2012-2030, into which the objectives of the Plan insert perfectly.

2.- Group of trained investigators: There is a small, but highly qualified group of researchers who were trained abroad in world-class centers in this area. In the last decade, they have carried out more than 70% of the work Chile has done to date. In the last five years, master's and doctoral degree programs have been created in which this same group, with international support, is currently educating new generations of researchers in the area.

3.- High quality of the existing infrastructure: The installed laboratory capacity in Chile is limited, but of good quality. 95% of the existing capacity is concentrated in four centers and the major and most important equipment has been designed and installed with the consultancy of important European reference centers. These facilities were conceived to achieve the best balance

between local information needs (Chile), costs and time involved in the different tests and trials.

4.- Regional leadership: Chile is one of the leaders of the region in the area. It was the first Latin American countries to introduce thermal regulations and a system of energy certification into its construction ordinance. Its per capita income and potential for investment to improve the quality of its dwellings is currently the highest in Latin America.

7.3.3. Opportunities:

1.- High national and regional (Latin America) demand for dwellings: The annual demand for housing in Chile verges on 150,000 units and the supply only covers 80% of this demand. In Latin America, the demand is 2.5 million and the supply covers 1.5 million according to IDB figures reported by the Habitat organization in 2013. The large-scale residential construction sector also has the lowest rates of technological innovation in the region. This is definitely an opportunity to develop new markets with solutions for better quality dwellings at competitive costs.

2.- Social demand for quality: Society demands higher standards of energy efficiency in its buildings. This condition is increasingly valued by markets in order to achieve the recognition and acceptance that buildings need as products that are bought and sold. Today, the real estate industry must satisfy a more informed, demanding client, with higher environmental comfort aspirations and a greater concern for the energy efficiency of his/her dwelling.

3.- Social appreciation of sustainability: Society increasingly requires safer, more habitable and more sustainable buildings. In Chile, the buildings

sector is responsible for 26% of final energy use, 34% of solid waste generation, 33% of greenhouse gas emissions, and 6% of water use. The design and construction of buildings should necessarily be founded on basic principles such as quality, energy savings and the optimization of the resources used.

4.- Demand for energy efficiency: In order to grow, the country needs greater amounts of energy and to disconnect its economic growth dynamic from that of energy consumption. Today, the challenge for Chile is to have sufficient, competitive energy resources and to improve the performance of energy use in all sectors, particularly in the buildings sector. Energy efficiency is an important part of the national strategy to achieve sustainable economic growth and social progress; in addition, there is a favorable environment and institutionality for the development of initiatives of this kind in the country.

7.3.4. Threats:

1.- Indiscriminate entry of foreign technologies: This involves the incorporation of construction materials and technologies into the local market without any degree of adaptation to the climatic, seismic, and cultural conditions of the national population; it is a situation that has in fact been occurring over the last five years: 12 of the 21 new construction systems follow these patterns and many of the new materials possess hygrothermal properties that seem incompatible with the climatic requirements of the south-central zone of the country, where there is the greatest volume of construction pathologies and quality flaws.

2.- Indiscriminate use of technical standards: There are only six mandatory technical standards to help regulate the energy performance of

dwellings in Chile, clearly an insufficient number. It is necessary to incorporate at least 20 more regulations, which are currently being studied. The strategy followed, with only a few exceptions, is to adopt an international standard, preferentially ISO, which is translated and labeled as a national standard. This has generated design errors and construction pathologies in many cases.

3.- Tax and trade barriers: Tax reforms in particular normally inhibit investment in Chile. Currently, a reform is being studied that seeks to increase the tax load to meet a collection goal of 3% of the GDP, which will probably affect the real estate sector, among others sectors.

4.- Economic recessions: Chile is the seventh most open economy in the world. It maintains a network of free trade treaties with 60 countries that connect it to a market of 4,302 million people and potential clients. For this reason, it is also very vulnerable to international capital flows and conflicts, which tend to cyclically affect its economy. Construction activity is an economic engine in Chile, a barometer for its state and the first and most affected by international crises.

7.4. General Objectives and Areas of Action in the Plan

The plan defines the main actions to develop in Chile in the next 10 years to improve the energy quality of its housing supply. For these purposes the "country organization" assumes the following objective, vision and mission:

The objective: To improve the energy and environmental quality of residential construction in Chile.

The vision: To have a supply of residential constructions that mainly integrates sustainability concepts and criteria, with buildings that have the capacity to limit the heating and cooling energy demand to acceptable minimum values. In summary, to have dwellings with acceptable energy quality attributes and a society with sufficient information to correctly decide on their purchase.

The mission: To contribute to the environmental and energy improvement of housing construction in Chile by perfecting the construction ordinances and their system of control and inspection, boosting sustainable construction and education in this area, and increasing the volume and quality of technological innovation work.

The goal: To have in Chile, by 2025, a large-scale supply of residential constructions that demand half the energy to provide thermal comfort as the 2011 housing supply, measured in the same way.

The plan involves all those in the residential construction industry and includes actions in the areas of research and development, policies and regulations, technological infrastructure, and education and training, among others.

7.5. Strategic Action Axes

The strategic axes derive from the SWOT matrix and from the strategies deduced from that analysis. The information derives from the review of the country organization's progress, achievements and pending challenges in terms of the quality of its residential constructions, which is reported in previous chapters.

Appendix 7 summarizes the SWOT matrix, which gives rise to the Strategic Axes. The axes group the most important topics and actions in order to improve the quality of dwellings in Chile.

Six Strategic Axes (S.A.) are defined thus:

Axis 1: Innovation and competitiveness
Axis 2: Sustainability
Axis 3: Habitat and welfare
Axis 4: Infrastructure
Axis 5: Education
Axis 6: Regulations and governance

7.6. Structure and Projection of the Plan

The structure and projection of the plan derive from the disintegration of each Strategic Axis into objectives, indicators and lines of action, as explained in the methodology.

7.6.1. Strategic Axis 1: Innovation and Competitiveness

7.6.1.1. Strategic Objective 01.1: To promote innovation and entrepreneurship in processes, housing construction systems and facilities that favor energy efficiency, sustainability and economic productivity in residential construction projects.

Specific Objective 01.1.1: To increase the volume and quality of the construction systems available on the market.
Indicators:

The number of new construction systems registered with DITEC MINVU.

Lines of Action:

LA 01.1.1.1.: To develop technological innovations in construction systems and processes with distinguishing sustainability attributes.

LA 01.1.1.2: To develop labeling and energy and environmental certification systems for materials, components, construction systems and facilities.

Specific Objective 01.1.2: To improve the energy efficiency and use of new technologies.

Indicators:

The number of new service facilities and systems on the market

Lines of Action:

LA O1.1.2.1: To develop efficient, low-cost hybrid or passive facilities to improve the environmental and energy performance of dwellings.

LA 01.1.2.2: To develop technological innovations to incorporate Net-Metering systems and zero net energy buildings (ZNE), among others, into the housing market in Chile.

LA 01.1.2.3: To develop innovations in the energy-management systems of dwellings and collective buildings.

7.6.1.2. Strategic Objective 01.2: To promote innovation and entrepreneurship in materials and building components used in housing that promote the energy efficiency, sustainability and economic productivity of residential construction projects.

Specific Objective 01.2.1: To increase the volume and quality of the materials available on the market.

Indicators:

The number of certified new materials and elements on the market.

Lines of Action:

LA 01.2.1.1: To promote a public database of certified materials, components, facilities and construction systems.

LA O1.2.1.2: To develop innovations in materials and elements with better energy and environmental performances (new, improved or adapted).

LA 01.2.1.3: To promote the development of nanotechnology applied to the energy and environmental improvement of materials.

LA 01.2.1.4: To promote the development of phase change materials to improve the energy quality of residential construction.

7.6.1.3.- Strategic Objective 01.3: To promote innovation and entrepreneurship in passive housing, resulting in dwellings better adapted to the climatic conditions in the nation and dwelling use culture in Chile.

Specific Objective 01.3.1: To improve the passive design and arrangement of urban dwellings in Chile by incorporating sustainability criteria.

Indicators:

Number of new architectural housing designs with sustainability criteria.

Lines of Action:

LA 01.3.1.1: To innovate in the architectural design and passive design strategies used in housing projects.

LA 01.3.1.2: To innovate in the urban design and passive use strategies in real estate projects (of sustainable neighborhoods).

Specific Objective 01.3.2: To improve the process of designing dwellings and neighborhoods in Chile.

Indicators:

The number of new dwellings and neighborhoods with an integrated design process.

Lines of Action:

LA O1.3.2.1: To innovate in housing design processes in Chile. To incorporate "performance based building design" criteria or others.

LA 01.3.2.2: To develop science and technology in the areas of solar protection systems and passive energy use in Chile.

7.6.1.4. Strategic Objective 01.4: To promote the sustainable construction industry and market.

Strategic Objective 01.4.1: To create technology-based businesses.

Indicators:

The number of new businesses created (Start-ups and spin-offs).
The number of new products on the market.

Lines of Action:

LA 01.4.1.1: To prompt the creation of government subsidies for the acquisition of new dwellings that incorporate certified sustainability criteria.

LA 01.4.1.2: To develop advertising and marketing plans for sustainable construction.

Strategic Objective 01.4.2: To increase the government support for the improvement of energy efficiency.

Indicators:

The number of subsidies awarded.

Lines of Action:

LA 01.4.2.1: To increase the number and amount of subsidies for the thermal overhaul of dwellings.

LA 01.4.2.2: To develop technological undertakings and incubate businesses linked to the sustainable construction market.

7.6.2. Strategic Axis 2: Sustainability.

7.6.2.1. Strategic Objective 02.1: To promote the incorporation of sustainability criteria into housing construction.

Specific Objective 02.1.1: To develop experimentally-based information to support the development of regulations and standards.

Indicators:

The number of new standards established.

LA 02.1.1.1: To develop applied science and research to develop information and criteria to define standards.

LA 02.1.1.2: To develop economic and social evaluations to support the establishment of environmental- and energy-demand standards.

Specific Objective 02.1.2: To develop new ordinances and/or to improve those already existing.

Indicators:

The number of new standards in the OGUC.

Lines of Action:

LA 02.1.2.1: To develop sustainable construction standards and systems for their accreditation.

LA O2.1.2.2: To develop regional itemized lists for construction with technical characteristics, adapted to the climatic and cultural conditions of each region (15).

7.6.2.2. Strategic Objective 02.2: Stimulate the adoption of the life cycle concept for the evaluation of housing construction.

Specific Objective 02.2.1: To increase the number of dwellings and materials with life cycle analysis on the market.

Indicators:

The number of locally-produced materials with life cycle analysis.
The number of dwellings that incorporate life cycle analysis.

Lines of Action:

LA 02.2.1.1: To develop local databases and tools duly adapted for the life cycle analysis of buildings in Chile.

LA 02.2.1.2: To develop and promote the use of systems of control of performance-based characteristics, quality assurance and sustainable certification.

LA 02.2.1.3: To develop and promote life cycle analysis in real estate projects and associated impacts as judgment criteria.

7.6.2.3. Strategic Objective 02.3: To promote the passive design of housing constructions and the use of Non-conventional Renewable Energy to meet their heating and/or cooling, ventilation and lighting needs.

Specific Objective 02.3.1: To strengthen the tendering method for dwellings in Chile with energy efficiency criteria.

Indicators:

The number of sustainable construction tenders.

Lines of Action:

LA 02.3.1.1: To promote the execution of sustainable construction tenders for social housing.

Specific Objective 02.3.2: To increase the number of dwellings on the market that incorporate designs and facilities with energy efficiency criteria.

Indicators:

The number of dwellings that incorporate non-conventional renewable energy.
Lines of action:

LA 02.3.2.1: To innovate in the designs of housing and passive use elements, in the different climatic zones in Chile.

LA 02.3.2.2: To innovate in the energy sources used in dwellings (incorporation of non-conventional renewable energy).

LA 02.3.2.3: To develop tools to evaluate energy and environmental performances, and to support housing- and facilities-design processes.

7.6.3. Strategic Axis 3: Habitat and Welfare

7.6.3.1. Strategic Objective 03.1: To contribute to the improvement of the habitable quality of residential construction.

Specific Objective 03.1.1: To improve the habitable quality of dwellings.

Indicators:

The number of indoor climate standards.

Lines of action:

LA 03.1.1.1: To develop the basic science of adaptive comfort that is applicable to residential buildings in Chile.

LA 03.1.1.2: To develop and validate acceptable standards of indoor climate for dwellings in Chile.

Specific objective 03.1.2: To improve the regulation and control of indoor climate and facilities.

Indicators:

The number of facilities developed to control indoor climate.

Lines of Action:

LA 03.1.3.: To develop automated, low-cost systems for the regulation and control of indoor climate.

7.6.3.2. Strategic Objective 03.2: To reduce the construction pathologies associated with the housing stock's poor hygrothermal behavior.

Specific objective 03.2.1: To develop new tools for the control and analysis of pathologies.

Indicators:

The number of pathology-related complaints.

Lines of Action:

LA 03.2.1.1: To develop and validate service methods to carry out the diagnosis of flaws.

LA 03.2.1.2: To develop and promote service methods for control, quality assurance and certification of hygrothermal behavior.

Specific Objective 03.2.2: To incorporate hygrothermal design criteria into the ordinances.

Indicators:

New ordinances with hygrothermal design criteria.

Lines of Action:

LA 03.2.2.1.: To carry out experimental studies on transport phenomena and develop simulation tools for predictive analytics.

LA 03.2.2.2.: To develop hygrothemal design criteria and design solutions adapted to the country's climates and dwelling-use cultures.

LA 03.2.2.3: To develop hygrothermal zoning and hygrothermal design recommendations to prevent pathologies.

7.6.3.3. Strategic objective 03.3: To reduce the levels of emissions and contaminants that impact environmental comfort.

Specific Objective 03.3.1: To increase the use of systems that help in decontamination.

Indicators:

The number of dwellings with decontamination systems.

Lines of Action:

LA 03.3.4: To develop and encourage the use of systems that separate solid waste and organic matter in dwellings and buildings.

LA 03.3.1: To implement an emission-labeling system for heating and sanitary hot water production facilities.

Specific objective 03.3.2: To possess more detailed environmental information to decide on the use of materials and facilities.

Indicators:

The number of dwellings with materials and appliances with low or zero emissions.

Lines of Action:

LA 03.3.2.1: To develop solutions to reduce noise, light and air pollution and among others, which affect indoor climate.

LA 03.3.2.2: To reduce the use of polluting materials and appliances.

7.6.4. Strategic Axis 4: Infrastructure.

7.6.4.1. Strategic Objective 04.1: To support investment in applied research and development in sustainable construction.

Specific Objective 04.1.1: To increase the volume and quality of R&D.

Indicators:

The number of projects awarded.

Lines of Action:

LA 04.1.1.1: To develop three thematic R&D competitions on the sustainable construction of residential buildings.

LA 04.1.1.2.: To promote the university-business link for sustainable construction.

Specific Objective 04.1.2: To increase the number of centers created and/or dedicated to R&D.

Indicators:

The number of new Centers dedicated to R&D tasks.

Lines of Action:

LA 04.1.2.1: To give impetus to a governmental program for innovation and entrepreneurship in sustainable construction.

LA 04.1.2.2: To promote the development of new centers of excellence in R&D in sustainable construction and/or to strengthen the existing centers.

LA 04.1.2.3: To prompt the creation of the Chilean Sustainable Construction Cluster in the VIII Region .

7.6.4.2. Strategic Objective 04.2: To support investment in the creation of laboratories to support the processes of research, inspection and control.

Specific Objective 04.2.1: To improve the country's reference laboratory capacity.
Indicators:

The number of new laboratories created.

Lines of Action:

LA 04.2.1.1: To advance a governmental program for the installation of a quality accreditation laboratory in the regions where no such center is found and to strengthen existing centers.

LA 04.2.1.2: To install common, standardized quality accreditation techniques and protocols in all the laboratories in Chile.

LA 04.2.1.3: To develop and advance new methods and tools to support processes of quality supervision.

Specific Objective 04.2.2: To create a modern national accreditation system that covers the entire country.

Indicators:

A National Accreditation System present in the 15 regions.

Lines of Action:

LA 04.2.2.1: To reinforce the national quality accreditation system to cover the entire country.

LA 04.2.2.2: To develop service management systems for quality accreditation, to deliver opportune services at reasonable prices.

7.6.5.3. Strategic Objective 04.3: To support investment in the training of advanced human capital.

Specific Objective 04.3.1: To increase the country's critical mass.

Indicators:

The number of new master's and doctoral degree holders in the area.

Lines of Action:

LA 04.3.1.1: To encourage a governmental program to finance the training of advanced human capital, in Chile and abroad.

LA 04.3.1.2: To promote and advance the creation of new master's and doctoral programs in Chile that address topics in sustainable construction.

7.6.5. Strategic Axis 5: Education.

7.6.5.1. Strategic Objective 05.1: To improve technical and professional competencies in sustainable construction.

Specific Objective 05.1.1: To improve the technical and professional capacities of the personnel and of the country in the area.

Indicators:

The number of new technicians, professionals and other trained personnel.

Lines of Action:

LA 05.1.1.1: To develop and execute training programs in sustainable construction for university and technical degrees.

LA 05.1.1.2: To develop and execute workshops and seminars on sustainable construction topics for different audiences.

LA 05.1.1.3: To train the government's and industry's supervisory units, in quality control techniques for residential construction.

Specific Objective 05.1.2: To improve the country's training programs and methods of teaching, learning and technological transfer in the area.

Indicators:

The number of new training programs.
The number of programs that include sustainable construction subject matter.

Lines of Action:

LA 05.1.2.1: To develop new learning-teaching methods and models of technological transfer to favor the adoption of sustainable construction technologies.

LA 05.1.2.2: To encourage the creation of professional and technical certifications, in the different areas of sustainable construction.

7.6.5.3. Strategic Objective 05.3: To teach and raise awareness about sustainable construction in the entire construction collective, for the appreciation and creation of a sustainable construction culture.

Specific Objective 05.3.1: To raise awareness in society with the Plan.

Indicators:
The number of awareness seminars.

Lines of Action:

LA 05.3.1.1: To carry out awareness programs aimed at the population, industry and political authorities.

LA 05.3.1.2: To prompt the establishment of national and international cooperation networks, to favor the transfer and adoption of best practices.

LA 05.3.1.3: To advance public information platforms, to make plain and validate information related to sustainable construction.

Specific Objective 05.3.1: To possess different kinds of manuals, techniques and documents, to support design, construction and dissemination processes.

Indicators:

The number of teaching and dissemination manuals and documents.

Lines of Action:

LA 05.3.1.1: To develop specialty manuals and different kinds of documents, to favor the teaching, learning and dissemination of sustainable construction.

7.6.6. Strategic Axis 6: Regulations and Governance.

7.6.6.1. Strategic Objective 06.1: To update and perfect the Thermal Regulations for Housing (T. R.)

Specific objective 06.1.1: To possess Thermal Regulations that promote quality and innovation.

Indicators:

The incorporation of improved standards into the T.R.
The number of new standards incorporated into the T.R.

Lines of Action:

LA 06.1.1.1.: To carry out experimental research to support the incorporation of standards into the T.R. technically, economically and socially.

LA 06.1.1.2.: To define and incorporate new standards into the T.R. and to improve the current regulations.

LA 06.1.1.3: To develop new T.R., more in line with the current state of this type of instrument in the world.

LA 06.1.1.4: To establish zoning for architectural design purposes, that associates zones with requirement classes in a better way.

Specific objective 06.1.2: To periodically evaluate and update the T.R.

Indicators:

Annual evaluation reports.

Lines of Action:

LA 06.1.2.1: To develop and promote a public-private system to monitor, review and periodically update the T.R.

LA 06.1.2.2.: To perfect the MINVU tools CCLT_CL_V2 and CEV_V_1.0 used for energy ratings in dwellings.

7.6.6.2. Strategic Objective 06.2: To improve the support for technical standards in the Thermal Regulations for Housing.

Specific Objective 06.2.1: To develop experimentally-based information to support the establishment of regulations and standards.

Indicators:

The number of new standards incorporated into the ordinances.

Lines of Action:

LA 06.2.1.1.: To carry out experimental research to adapt international requirement standards, when possible.

LA 06.2.1.2: To create new national standards duly supported by locally-developed knowledge, or to directly adopt international standards, especially testing standards.

Specific Objective 06.2.2: To consolidate the institutionality of the creation of standards and regulations.

Indicators:

The number of new standards incorporated into the ordinances.

Lines of Action:

LA 06.2.2.1: To develop and implement a modern public system of accreditation of housing quality requirements.

LA 06.2.2.2: To perfect the system of study, creation and incorporation of standards into the construction ordinances.

LA 06.2.2.3: To foster government financing for the study and creation of standards of public interest.

7.6.6.3. Strategic Objective 06.3: To implement the Development Plan and monitoring and evaluation system.

Specific Objective 06.3.1: To create and consolidate the Development Plan's institutionality.

Indicators:

A defined body responsible for coordination.
The installed monitoring and management system.

Lines of Action:

LA 06.3.1.1: To establish and consolidate the Development Plan's management and coordinating institutionality.

LA 06.3.1.2: To establish a management and evaluation system for the development plan, that enables evaluations in the mid- and long-term.

Specific Objective 06.3.2: To promote the coordination, cooperation, financing and execution of the plan.

Indicators:

The number of institutions participating in the plan.

Lines of Action:

LA 06.3.2.1: To prompt instances of coordination and cooperation between the actors involved in the Development Plan.

LA O4.3.2.2: To prompt instances of public-private cooperation, to produce financing, development and promotion of the plan.

7.7. Matrix of Strategic Projects and Actions

Finally, the Plan is structured based on the six strategic axes and 76 actions, including projects, programs and promotion and dissemination initiatives, grouped by the different axes that should materialize or at least begin during the 2015-2025 period.

In a country like Chile that is in the process of development and also has urgent needs in several other sectors, resources are by definition scarce.

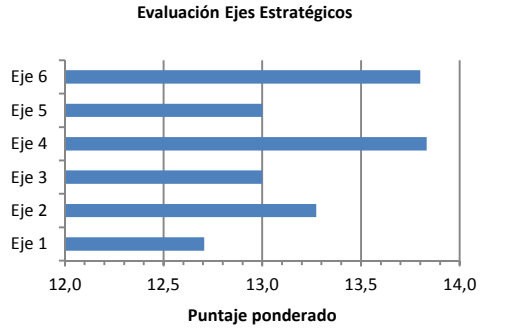
The authority responsible for administering the plan and the political authorities, should by all means prioritize considering the resources available and the "relative urgency and impact" of the initiative in the reduction of gaps according to the country's state and development in the area. The

quantitative and qualitative evaluation carried out was done precisely to help authorities make complex decisions of this nature.

Figure 7.4 presents the evaluation of plan's strategic emphases.

Figure 7.5 shows the conceptual map of prioritization that integrates the quantitative and qualitative concepts used to evaluate priority.

Appendix 8 presents the Strategic Objectives Matrix, which associates objectives and lines of action and the type of prioritization the plan assigns to each initiative. The quantitative weighting goes from 6 to 18 and the qualitative weighting from A to C, and the highest priority is 18 A and the lowest priority is 6 C, according to the method developed.



ID	Nombre Eje Estratégico
Eje 1	Innovación y competitividad
Eje 2	Sostenibilidad
Eje 3	Hábitat y bienestar
Eje 4	Infraestructura
Eje 5	Educación
Eje 6	Regulaciones y gobernanza

Figure 7.4: Evaluation of priority of the Plan's different strategic axes

At qualitative level A (a high priority project or initiative) and with a weighting close to 18 points, there are several initiatives from the axes regulations and governance, and Infrastructure.

In the lower levels of project or initiative categories, at qualitative level C (Low Priority) and with scores between 7 and 10 points, there are initiatives

in the self-generation of energy and designs and systems for zero net-energy buildings development lines, among others. This situation that takes into account the importance that specialists attribute to other, unresolved, basic problems in Chile. Particularly, that of reducing the energy demand of the stock is the first and greatest challenge.

All this information should be useful for the authority that takes charge of the Strategic Plan's coordination and management, to work out the annual operating plans to execute the different actions included in the proposed Strategic Development Plan.

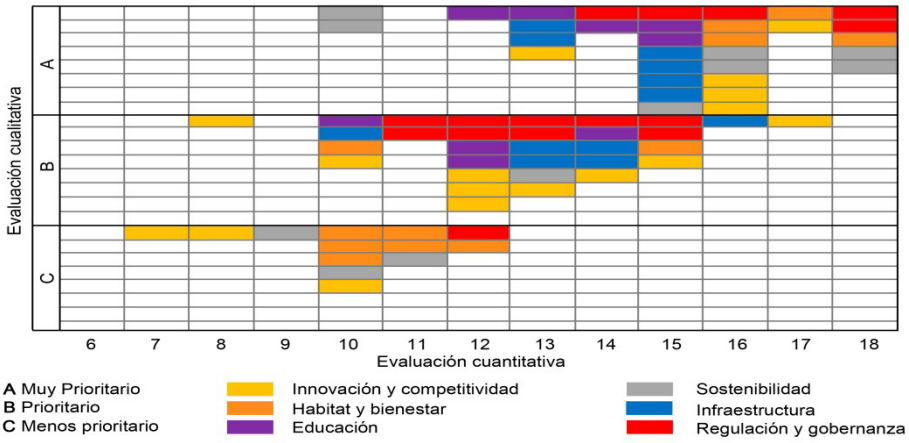


Figure 7.5: Conceptual map of prioritization of actions of the different strategic axes. Source: created by the author

Specialists' value assessment of the strategic axes is relatively similar; all the axes have very similar high assessments, which reflects the fact that Chile needs to advance complementarily in all the areas that the SWOT analysis identified to reach the plan's goal, which is: "To have in Chile, by 2025, a mass supply of residential buildings that require half the energy to provide thermal comfort as the supply in 2011, measured in the same way."

The axes regulations and governance and infrastructure are at the first priority level, which is explained by the need to first create appropriate conditions to improve energy quality. The country urgently needs to first perfect its regulatory framework. In this process, the State should take a much more active role in safeguarding general interest, as society currently demands. At this same priority level is the creation of the plan's institutionality, which should be in the Ministry of Housing and Urban Planning, in its Technical Directorate for the Study and Development of Housing, DITEC, a State entity responsible for ensuring the quality of residential construction in Chile.

R&D work should also be at the first priority level, with an emphasis on science and applied research to develop information and criteria to define standards; economic and social studies to justify the establishment of the standards; and work to raise awareness, which is also necessary to overcome the opposition Chile has historically had to the development of thermal regulations.

A perfected regulatory system and a modern system of quality accreditation should generate the synergies necessary to improve the quality of housing in Chile. It should also serve as the base of and driving element for an entire process of development and innovation leading to new products, processes and services destined to serve a market with higher quality demands. In turn, R&D work in Chile should manifest itself based on the social objectives of limiting energy demand and reducing energy consumption in the buildings sector and should not skip stages. The energy demand of the housing stock in Chile is excessively high; the first challenge should be to reduce that demand. This demand is not necessarily associated with the energy consumption of housing in the middle and low strata in Chile, which is the majority.

In thematic terms, work should preferably concentrate on the development of technologies to improve the supply of materials, construction systems, and conventional facilities available on the market. Then in successive stages, work should advance toward more complex objectives for which the necessary capacities should be generated previously, such as zero-energy buildings (ZEB) or zero net energy buildings (ZEN).

These initiatives lead to dwelling designs and microgeneration technologies to generate heat and electricity, enabling energy independence. They are still uncommon in developed countries. In Chile, these are issues that should be addressed in later stages and no sooner than 5 years.

7.8. Conclusions and Comments

The comments on and conclusions of the work of devising the development plan to improve the energy quality of the stock of new buildings in Chile is summarized as follows:

A program of actions has been established that defines strategic axes, objectives, goals, measurable indicators and a group of 76 actions to carry out in the next 10 years to reduce the gaps in energy quality in Chilean housing stock. Different strategic planning techniques were used to identify actions and prioritize them, with the assistance of a panel of experts. This information should help the authorities in charge to make decisions regarding the plan's management and execution.

The results of the evaluation of the plan's priorities show that the assessment of the priority of the strategic axes is high and relatively similar. All the axes are within the 12.7 (Innovation and Competitiveness) to 13.8 range (a similar

appraisal for Regulations and Governance and Infrastructure), within a domain that goes from 6 as the minimum appraisal to 18 as the maximum. Additionally, most of the plan's actions are within types A (Highest priority) and B (Priority).

This means that the country should advance on all fronts to reduce quality gaps, but with a strategic emphasis on the aspects of regulation and infrastructure, which is a reflection of its current state of development. Meanwhile, from the strategic map of actions it can be deduced that the actions should emphasize perfecting the regulatory framework. This includes all the R&D work in science and applied research to develop information and criteria to define standards, economic and social studies to justify the establishment of new and better standards, and work to raise awareness regarding the topic. At the same priority level are the actions intended to create better laboratory conditions to support the installation of a modern system of quality accreditation that also helps processes of investigation and training of human resources.

A perfected regulatory system and a modern system of quality accreditation should generate the synergies necessary to improve the quality of housing in Chile. It should serve as a base for and driving element of an entire process of development and innovation leading to new products, processes and services intended to serve a market with higher quality demands.

In Chile, R&D work should also be formulated based on the social objectives of limiting energy demand and reducing energy consumption in the buildings sector and should not skip stages. The energy demand of the housing stock in the country is excessively high; the first challenge should be to reduce that demand, which is not necessarily associated with the

energy consumption of dwellings in the middle and low strata in Chile, which is the majority.

In thematic terms, work should preferably concentrate on the development of technologies to improve the supply of materials, construction systems and conventional facilities available on the market, to then in successive stages, progress toward more complex goals such as zero-energy buildings (ZEB) or zero net energy buildings (ZEN).

These initiatives lead to dwelling designs and microgeneration technologies to generate heat and electricity, enabling energy independence. They are still uncommon in developed countries. In Chile, these are issues that should be addressed in later stages and not sooner than five years.

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8.0. SYNTHESIS AND CONCLUSIONS

This doctoral thesis aimed to investigate the topic of the environmental and energy quality of the housing stock in Chile.

At the moment in Chile, the convenience and timeliness of modifying the standards of thermal insulation of buildings, introducing other standards and, in general, upgrading and modernizing rules and ordinances are being discussed politically and technically. As such, the investigation of this topic seemed opportune. In particular, what motivated me was the possibility of carrying out a study that would help to develop criteria and evidence to give scientific support for the important strategic decisions that the country must make now, and also orient tasks and pending challenges in the area of energy performance of the housing stock in Chile.

In addition, considering the type of thesis of the program, it should also serve another purpose, which is to present for third party judgment my contribution to the development of building physics in Chile and, through the strengthening of this science, to the innovation and technological development in the area.

Having explained the general context and objectives, there were basically two main centers of attention in this thesis:

1. "To perform a critical analysis of the trends, achievements and remaining challenges in energy and environmental quality in relation to buildings intended for housing in Chile…"

On the basis of said analysis, which covers the period from 1982 to 2012, and with knowledge of the energy quality of the mass supply of housing in 2011, the following activity had to be undertaken as part of the thesis:

2.- "to design and propose a strategic development plan, which defines objectives and a set of prioritized actions to perform during the period 2015-2025, with the objective of reducing gaps and to improving the energy quality of the housing stock in Chile."

This work set out a series of questions, which can be basically summarized into four:

1.- What is the energy quality of the residential buildings that the housing market offers in Chile today and what is the quality gap?

2.- How have research, technological infrastructure and regulations evolved? Have they responded to the needs of society?

3.- What modifications have occurred in the thermal, hygrothermal, acoustic and other properties of the materials and construction systems and how have they impacted the energy quality and indoor climate of dwellings?

4.- What are the main challenges in terms of research, regulations, training, quality control, policies, others, and what can this study recommend in this regard?

Below, the synthesis and the main conclusions of this thesis are presented, taking into account the framework of objectives and the questions that it sought to answer:

8.1. Energy Quality of the Supply of New Buildings

Table 8.1 shows the base line of energy quality of the stock of new buildings registered in 2011 and two more references:

The first, the energy demand of the stock, considering the different types of construction and floor area in the 54 provincial capitals: 141 kWh/m² year. The second, the energy demand of the same stock, with acceptable standards of thermal insulation and airtightness: 74 kWh/m² year. The third, the demand of the current stock, considering standard infiltrations equal to 1 1/h, as commonly used in Chile in the absence of information on the airtightness characteristics of the stock: 123 kWh/m² year.

Figure 8.2 shows the gaps in quality by province, which are associated with the heating demands of the reference building stock.

The study concludes that the energy quality of mass housing construction in Chile is deficient. The evaluated sample, representative of a universe of 151,071 housing units (10,431,888 m²) registered in 2011 in the 54 provincial capitals of Chile, shows that this stock of buildings demands twice as much energy for heating than that which is strictly necessary. The quality gap, measured in energy terms for all of the buildings from that year is seen as important and amounts to 67 kWh/m² year.

The gaps in quality by province are also associated with heating demands. They are in the range of 0-259 kWh/m²year, with an average value of 74 kWh/m² year and their reduction is of primary interest. These gaps account for the existence of heterogeneous energy qualities and of varying degrees of importance; differences compatible with varying degrees of weather

severity, with construction types and with varying degrees of adjustment between construction types and designs with climatic requirements in each province.

This is the most accurate estimation of housing energy quality achieved to date in Chile and of gaps and quality distribution in the country. It is the result of an extensive study, which combined simulation techniques with other types of experimental techniques, in order to consider, for the first time in energy analysis, the real airtightness characteristics of residential construction stock.

The review and critical analysis of the current state of energy quality of residential buildings shows that:

1.- The thermal protections of residential constructions are low and very low in a large part of the nation and in the most populated areas. This situation can be explained mainly due to the existence of thermal regulations that require very low standards of protection.

2.- Residential buildings in Chile have a reduced capacity to resist air leakages. The sample under study yields values of n50 of 12.9 1/h, with expected values between 11.1 and 14.7 1/h and 95% reliability. This is a measure of the art and quality of sealing and the airtightness of residential buildings, which compare very poorly with the average standard in Europe, about 3 1/h. Airtightness is an unregulated feature in Chile and thus, is not controlled, which partially explains this performance.

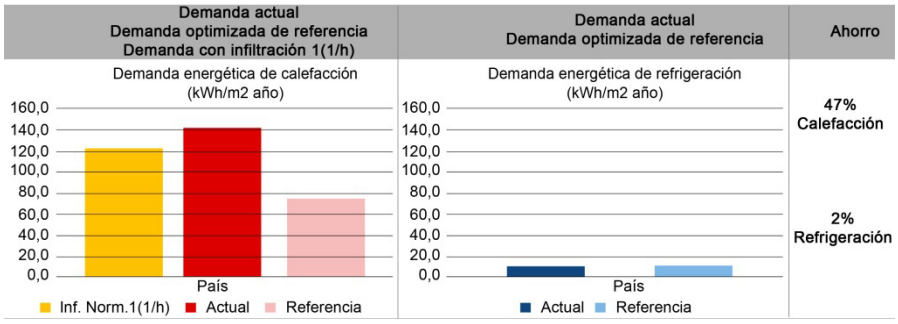
3.- The thermal protections are generally low, but in addition they are not adjusted to the requirements of location, which is reflected in the heterogeneity of gaps and different aptitudes that the dwellings in the

different provinces show. This is also a result of errors in the thermal zoning in Chile, which delivers inaccurate design guides for some areas of the country, as previously explained.

All these findings question the activities and progress of the country on several fronts. The levels of quality that mass residential construction exhibits in Chile are not up to the demands of modern societies. At least, they are not up to the country's current level of economic and technological development.

In summary, one of Chile's major challenges is to raise the standards of thermal protection in residential buildings, to incorporate new requirements to regulate aspects such as airtightness, thermal comfort, ventilation and others not yet covered, and undertake a group of other complementary actions which will be explained later.

Table 8.1: Baseline of the energy quality of the housing stock from 2011 in Chile. Current demand, reference (optimized) and with infiltration 1 1 1/h.



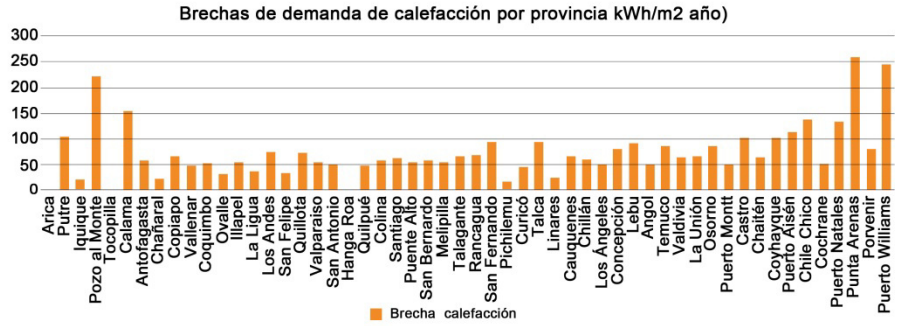


Figure 8.1: Quality gaps in the building stock in 2011 associated with heating demands

8.2. Evolution and Response of the Research Activity

Figure 8.2 shows the development and evolution of the R&D&i activity in Science (Fondecyt Projects), Applied and Development Research (Fondef Projects) and Development and Business Venture research (Innova CorfoProjects), during the 1982-2012 period.

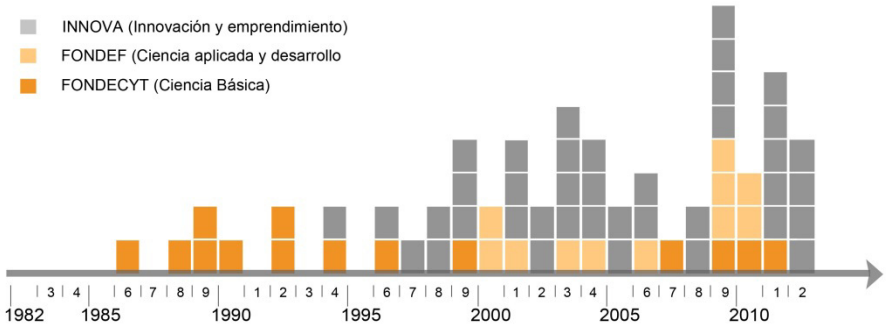


Figure 8.2: Research activity, development and innovation in sciences and technologies of the construction of dwellings in Chile, 1982-2012 period.

The most distinctive features of this study are the following:

1.- The investment in R&D in Chile is low, and particularly low in the technology area of housing. Chile invests 0.4% of its GDP in all areas, a fifth of the average in OECD countries, of which Chile is a member. In the area of housing, during the 1982-2012 period Chile invested 0.38% of the total resources that were destined for research. These resources funded 64 projects in science and technology along the lines of the competitive fund projects described previously. This is a relatively low volume of investment, considering that investment in residential construction averaged 5% of the national GDP during the observation period.

2.- A balance is observed among projects of public interest aimed at resolving problems of information asymmetries and market failures, and projects of productive interest focused on the development of diverse innovations for purposes of commercial exploitation. In terms of the type of innovation, product innovations (48%), which are related to the development of materials and building components such as bricks, mortars, panels, etc., and processes (43%), which are associated with new or improved construction systems, prevail.

3.- The areas of work that show greater prevalence are the development of materials and building systems (61%); development of norms and standards (48%); quality management (32%) and construction physics (27%). More nascent or minor developments are visible in areas destined for studies of habitat and occupation of dwellings and those oriented to the development of new and better of options of design and architecture for dwellings. By project type, 22% are categorized as science, 11% as applied research with a minor development component and 61% as development and business venture, mainly.

4.- The R&D capabilities are observed to be very concentrated; moreover, no more than 3 institutions carried out nearly 70% of the research that Chile shows during the period. The institutions with the most activity are: the University of the Bío-Bío, the Pontifical Catholic University of Chile, the University of Chile and the University of Concepción, in that order. The group of researchers responsible for the activity that Chile exhibits in the area (64 R&D projects during the observation period) does not exceed 40 investigators. Included as project directors and/or co-investigators with relevant participation, measured in terms of the number of appearances in the Conicyt and Corfo records, reduced to percentages, are: Ariel Bobadilla (34%), Gerardo Saelzer (16%), Ricardo Hempel (14 %), Waldo Bustamante (14 %), Leonardo Veas (11 %), Adelqui Fissore (8 %), Roberto Goycoolea (8 %), and Maureen Trebilcock (8 %).

5.- The innovative merit of the development activity is estimated as low. Few innovations are the result of the application of new knowledge developed from major R&D efforts involving changes close to the technological frontier. This situation is clearly reflected in the market: about 80% of residential construction uses traditional, manual building systems, in concrete, brick and block masonry, with very few modifications in the past 30 years. 15% uses non-traditional systems that entered the residential construction market in the past 10 years. The majority are prefabricated systems based on SIP-type panels (Structural Insulated Panels), which have been introduced into the country without any degree of technological adaptation to local conditions.

Major changes are observed at the materials level, such as panels, siding, paints, wallpapers, different kinds of barriers, roofing, windows, and other finishing materials. The hydrological and thermo-physical properties of

many of these materials are unknown. The properties of other materials appear to be incompatible with the envelope designs used in Chile, considering the gradual emergence of building pathologies in dwellings of every level in the last decade (CITEC UBB, 2010, 2013a and 2013b).

The experience reviewed shows that most of the building envelope solutions fail to correctly relate the physical properties of the materials with the design, and this with the different climates in the country. The materials used have changed. The level of thermal insulation is somewhat higher, although still insufficient; however, the envelope designs are virtually the same and are used almost independently of climatic characteristics of place.

6.- Applied and development research has evolved based on the needs of the thermal regulations, on the quality construction Law and, mainly, on the construction industry. In Chile, investigators compete to carry out research and this requires industry backing for development research. Thus, the needs for this type of research have evolved according to the needs and culture of innovation in the construction industry, which is in the country a powerful industry, little inclined to innovation. This fact explains in part the low volume of research activity and the innovative character of the activity that Chile shows.

7.- The level of development that projects reach at their end and/or post-project phase is another distinctive aspect of research in the area. The return on investment in development research is still seen to be relatively low: less than 2 in every 10 research projects achieve products that are placed on the market (products, processes, services). Due to various circumstances, the majority does not exceed the phases of technology tested at the pilot level. This phenomenon is explained, among other reasons, by the lack of incentives to make investments that seek to make use of products that are the

result of innovation projects. These investments always involve some degree of risk that the industry, the financial system and the Chilean State are not always willing to assume.

8.- 72% of Chile's research in the area, and the most important, was carried out in the last decade. This is the result of the greater social demands during the period and, mainly, due to the greater supply and capacity for R&D which enabled investigators trained at foreign universities to practice research, in particular, those trained at the Catholic University of Louvain and the University of Liege in Belgium, and the University of Nottingham in England, among others. Researchers trained in Louvain are currently listed as responsible for over 50% of the research activity undertaken in the last three decades, as deduced from the number of appearances in the Corfo and Innova records.

In summary, the volume of research work carried out is very low and its effectiveness, measured in terms of placement on the market, is perceived to be moderate. While the ability to investigate in Chile has grown considerably in the last decade, there is not yet sufficient critical mass to meet the challenge of reducing the level of quality gaps that the housing stock currently exhibits.

In consequence, another of the country's major challenges is to improve the volume and quality of research activity in all areas and incorporate transversely all the developments in, and concepts and criteria of sustainability, to improve its social appreciation.

8.3. Evolution and Response of the Laboratory Infrastructure

Figure 8.3 shows the development and evolution of the installation of building physics laboratories in Chile, during the 1982-2012 period.

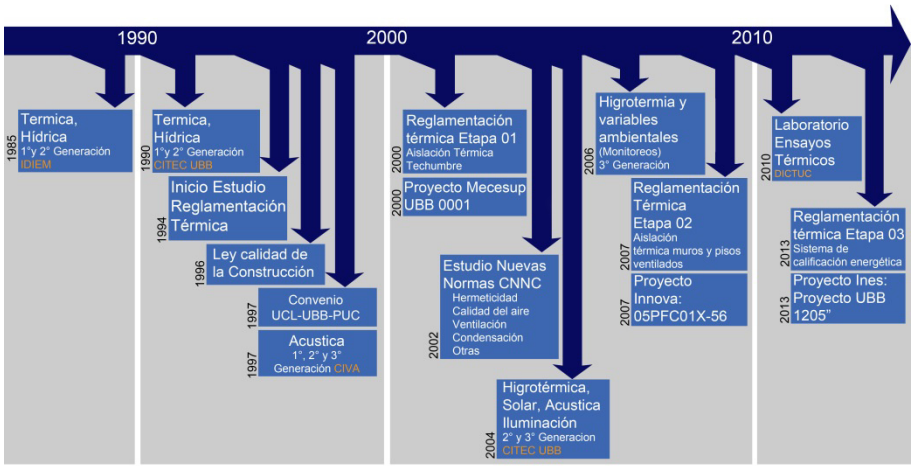


Figure 8.3: Milestones in the process of installation of building physics laboratories in Chile. Period 1982-2012.

The most distinctive features of this process are the following:

1.- The cadastre carried out showed that more than 95% of the building physics laboratory infrastructure is concentrated in only four centers. These include: the Center for Research in Construction Technologies at the University of the Bío-Bío, CITEC UBB; the Institute for Research and Testing of Materials at the University of Chile (IDIEM); the Directorate of Research in Science and Technology at the Catholic University of Chile, DICTUC UC; and the Center for Research on Southern Housing at Austral University, CIVA. Currently, the principal and most advanced facilities are located at CITEC UBB.

2.- Building physics laboratories are created in Chile to meet technical and social needs which have arisen in the country in the last three decades. The first facilities at IDIEM, in the beginning of the 1980s, were mainly for training purposes. Then, in the decade of the nineties, other centers were created for the same purposes and to meet other new needs. These needs included: scientific and experimental support to carry out studies on pathologies, in the framework of the construction quality law (1996); thermal testing of materials and construction components arising from requirements in the thermal regulations (2000 and 2007); and testing and analysis in the context of processes of research, development and/or adaptation of new materials, components and construction systems.

3.- The type and complexity of the facilities also evolved in the same way. In the beginning, first generation equipment and techniques were used to perform tests and studies of the properties of materials under controlled laboratory conditions, those of greatest interest in buildings physics at that time. Tests such as thermal conductivity, specific heat, moisture absorption and permeability to water vapor were carried out. Subsequently, and since the year 2004, facilities and experimental techniques considered as third generation have been incorporated. These are used for more complex, experimental studies of the hygrothermal, acoustic and light characterization of components and natural-sized buildings, under real weather conditions.

4.- The main testing and analysis techniques required to support research processes are installed. They also support a future system of quality accreditation which takes into account a broader range of requirements and verification needs. However, these capacities exist in very few laboratories and some in only one. This, added to the location of the laboratories within the nation, currently generates serious coverage problems. All laboratories

are located in the central area of the country and the nation extends 2,000 km to the north and south of where they are located.

In summary, the main challenges in this area are: to create new laboratories and/or strengthen existing ones in order to give support to the implementation of a national quality accreditation system that covers the entire country and to train specialist personnel. In addition, these laboratories serve to support the development of new material technologies and building systems. For these purposes, in the next few years it is necessary to put into operation at least five new reference laboratories.

At present, the work of incorporating new norms and regulations into the OGUC and development research are seriously limited by the lack of technological infrastructure. This is a critical weakness at this time that the development plan should prioritize very well.

8.4. Evolution and Response of the Ordinances

Figure 8.4 shows the development and evolution of the installation of building physics laboratories in Chile, during the period 1982-2012.

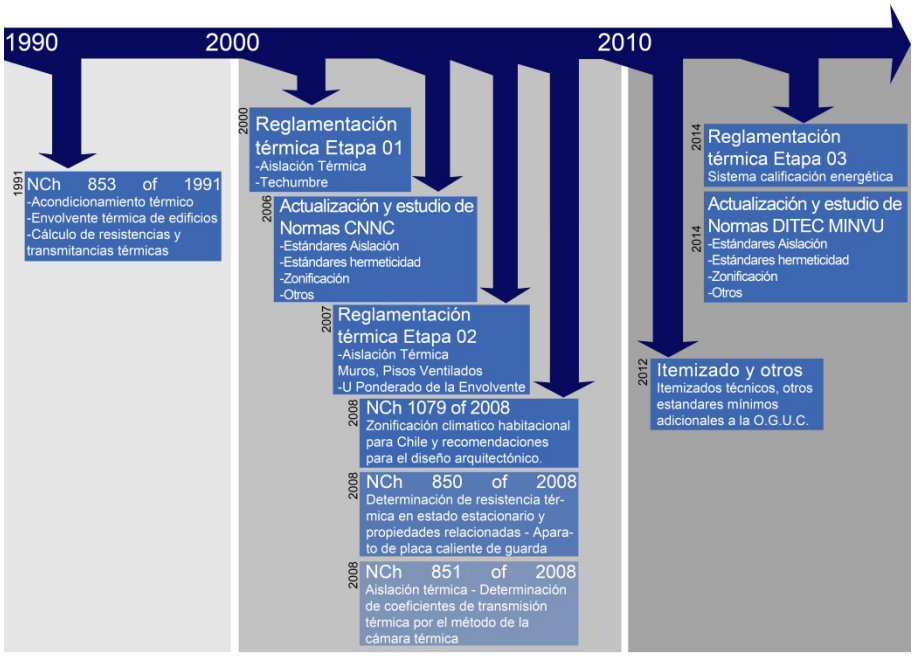


Figure 8.4: Emergence in time of regulations related to the energy performance of housing in Chile

The most distinctive features of this process are the following:

1.- The ordinance that regulates the energy performance of residential buildings is insufficient. Its development has been excessively slow, considering as well that it began in the year 1994 and is still under construction. It currently consists of thermal regulations and six supporting standards: two calculation standards, three testing standards and a zoning and design recommendation standard. At present, only the thermal insulation of the envelope is regulated and an energy rating system for housing is in the process of being implemented.

2.- The development of the regulations has been seriously affected by at least three main causes: the lack of technical laboratory support to verify required performances, given the country's limited existing capacity; the lack of

human resources prepared to meet the needs for testing and inspection of new requirements; and the traditional resistance from the industry against the incorporation of modifications that would mean increasing the energy quality requirements.

3. The thermal insulation standards required by the regulations are low, as has been pointed out. They do not compare well with those of other European ordinances that govern in comparable climates, nor with the standards that studies in Chile have been recommending for several decades. New standards are in the process of being incorporated, although this process also faces the difficulties mentioned.

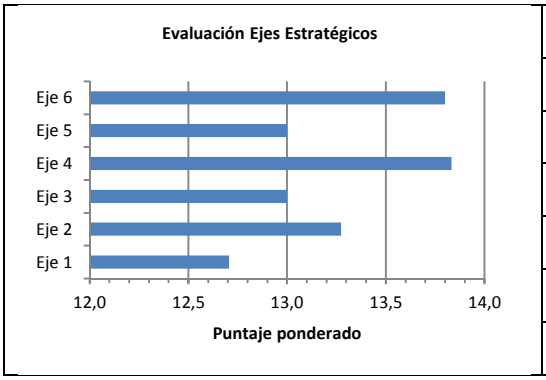
4.- The thermal regulations have influenced minimally the increase in quality of residential buildings. They have failed in their main aim, which is to help limit energy demand in a substantial way, as required by Chilean society. Advances in the field of the thermal quality of buildings are no longer considered important. This is aggravated by the fact that in the last decade the pathologies associated with hygrothermal problems have increase.

In summary: with the current state of development that the country exhibits, and observing international practice, it is urgent to incorporate into the regulations norms in the areas of thermal comfort, air quality, ventilation, air and water permeability, and the energy performance of buildings, among others. Similarly, improving the standards of thermal insulation and incorporating requirements to regulate the airtightness and hygrothermal behavior of residential buildings are also urgent. It will be impossible to achieve progress in the energy improvement of the housing stock if the regulatory framework is not previously improved.

8.5. The Strategic Development Plan and Future Challenges

Figure 8.5 shows the ranking of strategic themes, weighted quantitatively with the help of a panel of experts in the area.

Figure 8.6 shows the map of prioritization of lines of action that results from crossing the qualitative and quantitative evaluation. The actions of highest priority are located in area A (High priority) and have weighted values between 14 and 18 points.



ID	Nombre Eje Estratégico
Eje 1	Innovación y competitividad
Eje 2	Sostenibilidad
Eje 3	Hábitat y bienestar
Eje 4	Infraestructura
Eje 5	Educación
Eje 6	Regulaciones y gobernanza

Figure 8.5: Prioritization of strategic themes from the development plan.

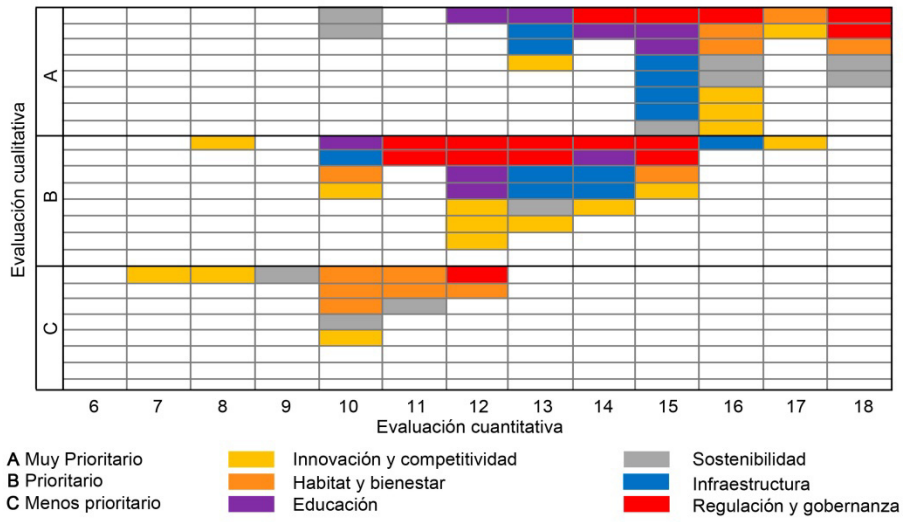


Figure 8.6. Map of prioritized actions from the Development Plan.

The most relevant conclusions are the following:

The value assessment of the strategic axes is relatively similar. This reflects the fact that Chile needs to move forward simultaneously in all areas identified by the SWOT analysis in order to achieve the goal of the plan, which is: "To have in Chile by the year 2025 a mass supply of residential buildings that require half the energy to provide thermal comfort as the supply in 2011, measured in the same way".

In a country like Chile that is in the process of development and has urgent needs, as well in several other sectors, resources are by definition scarce. In this way, prioritization should occur, considering available resources and the "relative urgency" of the initiative in the solution to the problem of the quality of residential construction in Chile, and the country's state of development in the area. The quantitative and qualitative evaluation carried out helps to establish the emphasis on axes and specific strategic issues; the most important are the following:

1.- In the first priority level are the axes of regulations and governance and of infrastructure, which are explained by the need to first create appropriate conditions to improve energy quality. The country desperately needs first to perfect its regulatory framework. In this process, the State should take a much more active role in safeguarding general interest as society currently demands. In this same priority level is the creation of the plan's institutional framework, which should be with the Ministry of Housing and Urban Planning, in its Technical Division for the Study and Development of Housing, DITEC, a State entity responsible for ensuring the quality of residential construction in Chile.

2.- In the first priority level should also be R&D work, with an emphasis on science and applied research to develop information and criteria to define standards; economic and social studies to justify the establishment of the standards; and work to raise awareness, which is necessary to overcome the opposition that the development of thermal regulations has historically had in Chile.

3.- A perfected regulatory system and a modern system of quality accreditation should generate the synergies necessary to improve the quality of housing in Chile. In addition to all this, a process of development and innovation should serve as the base and driving element, and lead to new products, processes and services, designed to attend to a market with higher quality demands. At the same time, the R&D work in Chile should be formulated based on the social objectives of limiting energy demand and reducing energy consumption in the buildings sector and should not skip stages. The energy demand of the housing stock in Chile is excessively high: the first challenge should be to reduce that demand, which is not necessarily associated with the energy consumption of dwellings in the medium and low strata in Chile, which is the majority.

4.- In thematic terms, work should concentrate preferably on the development of technologies to improve the supply available on the market of materials, building systems and conventional systems, to then, in successive stages, progress toward goals such as zero energy (EEC) or net-energy buildings (EEN). Initiatives leading to dwelling designs and microgeneration technologies for generating heat and electricity, which enable energy independence, are still uncommon in developed countries. In Chile these are issues that should be addressed in later stages and not earlier than 10 years.

8.6. My Contribution in the Area

I separate it into two parts: that made through this thesis work, and that which I have made since the year 1985, in which I started promoting research in Chile. Namely:

8.6.1. Contribution of the thesis work.

I highlight two contributions:

The first: Contribution to the knowledge of the energy quality of dwellings in Chile and the factors that explain it.

This contribution is achieved with the establishment of the baseline of energy quality of the new housing stock in Chile. It serves as the first measurement and reference of the development plan proposed by this thesis to reduce the gaps in quality, which needs to be evaluated periodically to measure its progress.

In this process two samples were evaluated: one, consisting of 191 houses representative of the housing stock built 2011, which was evaluated experimentally in order to know its airtightness characteristics (Bobadilla, 2014); the other, consisting of 20 projects representative of the housing architecture in Chile. Experimental techniques were used: Pressurization to obtain the airtightness of the samples; numerical models (LBL Model) to link the airtightness properties with the climatic characteristics of each province and obtain standardized infiltration coefficients by building type and province; and simulation techniques (Thermal Analysis Simulation Software) to determine the energy demand of the dwellings, by building type, by province, by thermal zone and country.

To establish quality gaps, the current quality of the stock is compared with reference qualities defined under the concept of limited use or minimum energy. Levels are established by using techniques and methods developed by this author previously (Bobadilla and others, 2012).

This energy assessment study of the stock is the most extensive to be carried out in Chile; it covers the 54 provincial capitals of the country individually and also considers, for the first time, the real airtightness characteristics of the building stock. It is recognized as the most accurate estimation of: the energy quality of dwellings obtained in the country, gaps in quality and geographical distribution of quality in Chile.

All this knowledge is applicable to the development of new designs and systems for the thermal conditioning of dwellings in Chile, which are better adjusted to the climatic requirements in each province of the country. Also, in a way I consider important, this knowledge is applicable to the development of criteria and judgments with scientific backing to define new and better standards of thermal protection for dwellings in Chile.

The second contribution of this thesis is a strategic development plan. This is a prioritized plan in 10-year periods, which is intended to improve the energy and environmental quality of residential construction in Chile. It is structured on the basis of axes, strategic objectives, goals, measurable indicators and lines of action for this social objective.

The goal of the plan is to reduce the value of energy demand that the base line reports today to half in a period of 10 years. The plan is conceived as a tool that guides political authorities as well as the academic and business worlds, as to what "the national organization" should do in order to achieve that goal.

In its construction, various strategic planning techniques such as SWOT and Balanced Scorecard (BSC), and qualitative and quantitative assessments with the help of a panel of experts were used, to define and prioritize strategic axes and lines of action. Finally, the plan is presented for the consideration of the Ministry of Housing and Urban Planning.

8.6.2. My contribution since the year 1985

I highlight contributions on two fronts in Chile: research and cultivation and development of experimental capacity in building physics.

8.6.3. In the area of research:

Figure 8.7 graphically illustrates my participation in the research activity carried out in Chile between 1981 and 2012. The year that each project started is indicated. The duration of each is normally between 18 and 36 months in Chile. I have participated as a collaborator or principal investigator in 22 of the 64 R&D projects carried out in the area in Chile, in

a process that I began in the year 1989 as the co-investigator of Fondecyt Project 89 0661 on the thermal behavior of dwellings.



Figure 8.7. Contribution of this author to research, development and innovation in sciences and technologies of residential construction in Chile, period 1982-2012

Since that date, I have carried out projects as the principal investigator in all areas ranging from basic science, through applied science with development goals, to development research with resulting products on the market.

Between the years 1989 and 1996, I participated in three Conicyt Fondecyt (science) projects in the area of hygrothermal design of envelopes and ventilation.

Through these projects, I have contributed to: the creation of an important part of the scientific knowledge about the design, and thermal and water protection of buildings that currently exists for the south central area of the country; the installation of experimental techniques for the physical-structural analysis of buildings, which were ground-breaking in the country and some of which are only currently available in CITEC UBB; and to build basic knowledge and scientific support in the discipline that I practice to

venture in the following years into applied research and development projects (Fondecyt 89 0661; Fondecyt 90 0213, Fondecyt 92 0263).

Regarding another aspect, the projects in this line have provided the scientific basis for implementing innovative services in construction pathology expertise, some unique in the country, which are rendered regularly through CITEC UBB at present. Some examples include: the evaluation of airtightness, a technique that was first established in Chile by this laboratory in the year 1992; the watertightness of facades; and the water topography of walls, among others.

Between the years 1994 and 2012, I participated in 15 Innova Corfo projects (development and entrepreneurship) in the areas of development of new materials, building systems and methods, and analysis tools.

Here I highlight some of the projects that gave rise to products (results) placed on the market: the construction technology of ferrocement housing (Fontec Project Number 193-0273 and Innova Project Number 99CT3-V03); HIT technology for housing construction (Innova Project Number 01-A1-022); the heat resistant concrete block technology used for the first time in Chile in the construction of the CITEC UBB corporate building (Innova Project Number 06-PCS1-004); the solid wood nailed system (Innova Project Number 03-A1-184); service methods to select windows in Chile according to climate and exposure conditions (Innova Project Number C9CT-03); methods for monitoring energy and environmental variables of buildings (Innova Project Number 09 CN14-5706).

Between the years 2003 and 2012, I participated in 4 Conicyt Fondef projects (applied research and development) in the areas of materials

development, building systems, development of quality certification methods and development of standards and technologies.

Here I highlight, as done previously: heat resistant ceramic brick technology (Patent Number 2738-2004); heat resistant ceramic mass technology (Patent Number 1939-2005); the insulating stucco mortar technology Dry Mix; new masonry systems (Fondef Project D01I116); a quality assurance system for housing construction projects based on criteria and performance standards (Fondef Project D09 I 1162); standards of air tightness and classes of acceptable infiltration in buildings by territorial zone in Chile, standards that were recently incorporated into a MINVU Technical Regulation, and technological solutions to support the design and construction of projects with acceptable classes of airtightness, which were synthesized in a specialty manual, the first of its kind in Chile (Fondef D10 I 1025); a wooden building technology, and systems with Passive House standards and specialty manuals (Fondef D10 I 1025).

On another complementary front, I have carried out a substantial amount of dissemination and transfer work, in the form of consultancy, training, creation of manuals and technical documentation regularly used as a reference texts in Chile, and other activities that support the processes of transfer and adoption of the technologies mentioned above. Several other projects failed to generate products feasible for commercial exploitation, for very different reasons.

Through the development of Fondef- and Innova-type R+D+i projects, I have contributed to generating patents and developing products, processes and services with a presence in the market today, and methods of evaluation and analysis of performances that are used regularly by the industry and academia.

The materialization of the projects indicated, all obtained with external competitive funds, has enabled the creation and consolidation of an important scientific and technological capacity for research and development work in physics and construction technologies at the University of the Bío-Bío, and specifically at its Center for Research in Construction Technologies, CITEC UBB, which stands out in Chile at present. A research group that is on the forefront in the country and top-of-the-line, specialized infrastructure, position this Center as the first reference in the nation in the area of Building Physics. All these capabilities have helped to increase the volume and quality of the University of the Bío-Bío's contribution to society, as well as its image and influence in the national sphere.

8.6.4. On the development of experimental capability in building physics:

In this area, I highlight my contribution to the development of the practice and experimental cultivation of building physics in Chile. The practice and cultivation of building physics is the scientific basis of the product development research previously presented. Likewise, building physics is also the scientific support for research in building pathologies associated with hygrothermal problems in Chile. This work is linked to legal trials in courts of justice, in some cases.

The need for research and studies associated with construction involve physical processes that, because of their complex nature, require experimental observation. For example, "HAM-effects" are of great scientific interest for me. At the time, they motivated me to create and install a specialty laboratory and begin in the year 1985 the first line of experimentally-based research in building physics in Chile.

Through various research and technological infrastructure projects, and with the counsel and international cooperation of the Center for Research in "Architecture and Climate" at the Catholic University of Louvain (UCL, 1997), I helped over the years to create at the University of the Bío-Bío laboratory infrastructure to support research and training processes in building physics.

An important milestone in this process of installing capabilities was my Master's degree program in the year 2000 at the UCL. The thesis was on the "development of test modules for experimental work in physics applied to buildings in Chile". This work enabled the development of the technical information necessary to design, implement and operate test modules or "Test Cells" for experimental analysis of transport phenomena (HAM Transport), under real climate conditions, of natural-sized building component prototypes. These units have been available at CITEC UBB since 2004. They were the first and are the most important third-generation units for experimental work in building physics currently available in Chile.

At the time, the modules were conceived to achieve the best balance between local information needs (Chile), costs and time involved in the thermal, water and solar testing of building components of natural size, under real weather conditions. The main reference source was derived from the project VLIET Test Building, developed by the Laboratorium Bouwfysica Van at K.U. Leuven and from the European Commission's PASSYS Program, a cutting-edge program at the time, in the area of experimental work in building physics in the world.

Another milestone that I emphasize in this process was Innova Project 05PFC 01X-56, which made it possible in the year 2006 to realize an important investment in new and improved technological infrastructure, and

change from the category of leading research group to the Center for Research in Construction Technologies, CITEC UBB, a research, development and transfer unit that is currently on the official register of Research Centers in Chile. I helped with its creation and am the present director and answerable to the superior authority of the University of the Bío-Bío and the Chilean Economic Development Agency, Corfo.

The project provided for, in addition, the construction of a building-laboratory that would fulfill a double purpose: house part of the technological equipment and the Center's management and, at the same time, serve as an illustrative laboratory on sustainability and energy efficiency topics, which are today important areas of work for the unit. This building concentrates innovative design and equipment technologies explained in chapter 6. It is considered as a reference of the country's current state of research and development regarding energy efficiency and sustainable construction.

All things considered, I have contributed in the past 25 years to the creation at the University of the Bío-Bío of the country's most complete infrastructure to support the development of the Construction Industry in the areas of the Center's work, which are declared to be building physics and sustainable architecture and building.

In recognition of the contribution of this author, as highlighted in this historical count, he was awarded the 2006 Municipal Prize in Applied Research with a Mention in Construction Physics. This prize was given by Decree 1006 from the Illustrious Municipality of Conception, dated September 29, 2006, due to "his vast work in the innovation of materials and building systems and the configuration of quality systems based on performance of construction products such as windows and doors".

8.7. References

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Anexo 1 **:** Tipologías constructivas presentes en cada una de las 54 capitales provinciales de Chile (en porcentaje %)

	T1: VAL1A	T3: VAL2A	T2: VAL1P	T4: VAL2P	T5: VH1A	T6: VH2A	T7: VDHYL	T8: VBd1A	T9:VBd2A	T10:VBd2P	T11: VM1A	T13:VM2A	T12:VM1P	T14:VM2P	T15:VPS1A	16:VFd1A	17:VFd2A	T18:VFd2P	T19:VALM2A	T20:VALM2P
Ciudad																				
Arica				70%			30%													
Putre (año 2008)								100 %												
Iquique							65%			35%										
Pozo Almonte	3%							97%												
Tocopilla									100 %											
Calama		15%				19%	66%													
Antofagasta						10%	90%													
Chañaral								96%	4%											
Copiapó		32%					68%													
Vallenar	14%	27%					49%	9%												
Coquimbo	9%	24%			8%		60%													
Ovalle	65%		35%																	
Illapel	58%	5%	17%								14%								5%	
La Ligua	19%					8%	42%				23%	9%								
Los Andes	5%	25%					70%													
San Felipe	50%			22%	14%		14%													
Quillota	16%	21%	12%	19%			12%				4%			14%						
Valparaíso		15%					80%												5%	
San Antonio	3%						47%				36%	9%					2%		2%	
Hanga Roa								28%			38%					33%				
Quilpué	9%	7%	8%	24%		13%	24%												7%	8%
Colina	7%	20%		33%		11%			7%			21%								
Santiago		12%				4%	84%													
Puente Alto				55%																35%
San Bernardo	12%	34%		19%					18%										17%	

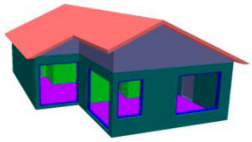
Melipilla	16%	16%					32%				13%				15%	8%				
	T1: VAL1A	T3: VAL2A	T2: VAL1P	T4: VAL2P	T5: VH1A	T6: VH2A	T7: VDHYL	T8: VBd1A	T9:VBd2A	T10:VBd2P	T11: VM1A	T13:VM2A	T12:VM1P	T14:VM2P	T15:VPS1A	16:VFd1A	17:VFd2A	T18:VFd2P	T19:VALM2A	T20:VALM2P
Ciudad																				
Rancagua	27%	32%	19%																10%	11%
San Fernando	56%			9%							11%						11%		12%	
Pichilemu	48%										34%	8%			11%					
Curicó	32%		26%	25%						9%	7%									
Talca	18%			15%			45%												22%	
Linares	43%		30%								15%								6%	5%
Cauquenes	33%		22%	21%						7%									7%	10%
Chillán	8%			10%							25%	25%		20%					8%	5%
Los Ángeles											33%	17%		31%					13%	6%
Concepción		23%				7%	13%				6%	5%					10%		35%	
Lebu											48%			27%					25%	
Angol	6%										69%	11%	14%							
Temuco							8%	8%	17%		47%	13%							7%	
Valdivia							7%				61%	32%								
La Unión							5%				84%	11%								
Osorno		7%									51%	42%								
Puerto Montt		7%									26%	14%				24%	29%			
Castro											68%	32%								
Chaitén											79%	21%								
Coyhaique											8%			19%		16%	52%	4%		
Puerto Aysén											41%	31%						29%		
Chile Chico	30%										70%									
Cochrane											16%	84%								
Puerto Natales											49%	22%	28%							
Punta Arenas											18%	11%	13%	30%			14%	14%		
Porvenir	42%										25%	33%								
Puerto Williams														50%			50%			

Anexo 2: Modelos de arquitectura más característicos del parque de construcciones habitacionales del año 2011

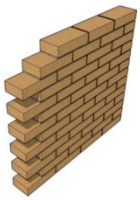
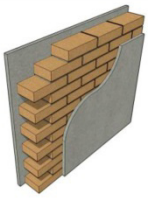
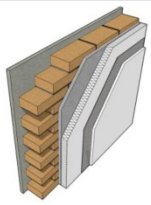
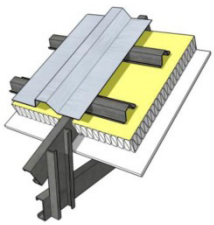
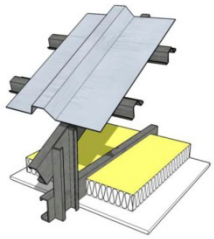
TIPOLOGÍA	Nº 1	CÓDIGO	VAL1A

Descripción	Vivienda de albañilería de ladrillo de un piso, aislada.

Superficie	66 m^2	Superficie envolvente	187 m^2	Superficie ventanas	15.7m^2	Volumen	138 m^3	Factor de Forma	1,36

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 14 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 2,5 - 0,6** **U techo : 0,84 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

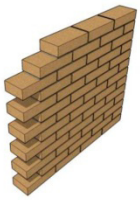
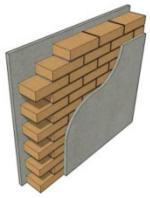
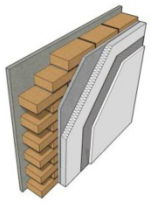
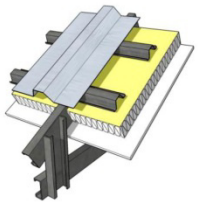
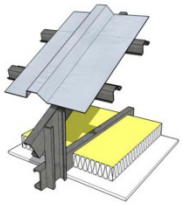
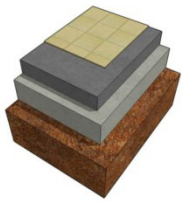
TIPOLOGÍA	Nº 2	CÓDIGO	VAL2A

Descripción	Vivienda de albañilería de ladrillo de dos pisos, aislada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

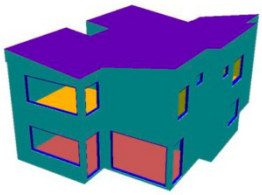
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 14 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 2,5 - 1,1** **U techo : 0,84 - 0,38** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

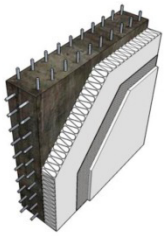
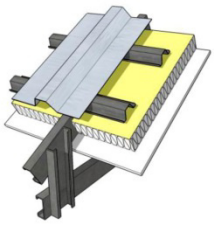
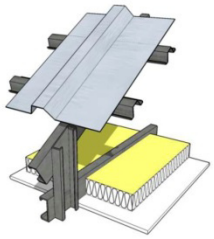
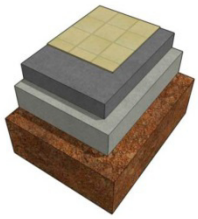
TIPOLOGÍA	Nº 3	CÓDIGO	VH2A

Descripción	Vivienda de hormigón armado de dos pisos, aislada.

Superficie	148 m^2	Superficie envolvente	352 m^2	Superficie ventanas	35,8 m^2	Volumen	318 m^3	Factor de Forma	1,1

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

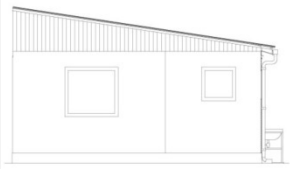
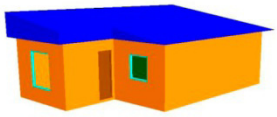
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 20 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,7** **U techo : : 0,84 - 0,38** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

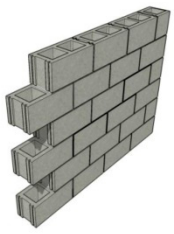
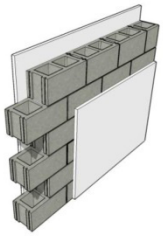
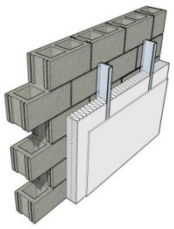
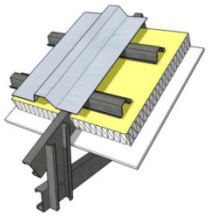
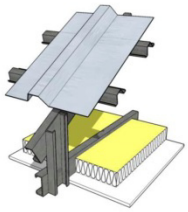
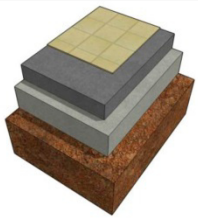
TIPOLOGÍA	Nº 4	CÓDIGO	VBC1A

Descripción	Vivienda de bloque de cemento de un piso, aislada.

Superficie	50 m^2	Superficie envolvente	166 m^2	Superficie ventanas	4,6 m^2	Volumen	105 m^3	Factor de Forma	1,6

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

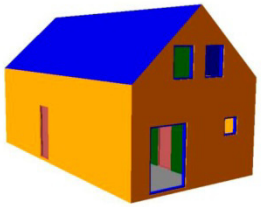
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 19 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

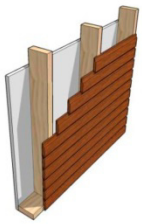
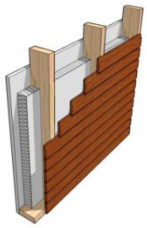
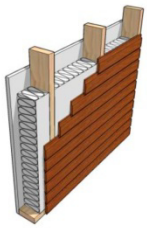
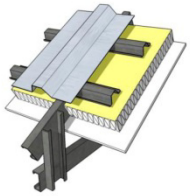
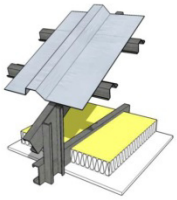
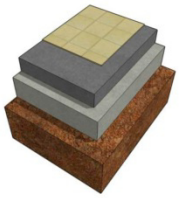
TIPOLOGÍA	Nº 5	CÓDIGO	VM2A

Descripción	Vivienda de madera de dos pisos, aislada.

Superficie	80 m^2	Superficie envolvente	196 m^2	Superficie ventanas	4,95 m^2	Volumen	172 m^3	Factor de Forma	1,13

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

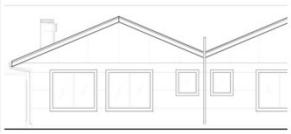
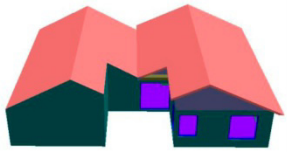
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 0 mm.	**Muro simple** Espesor 50 mm.	**Muro con refuerzo térmico** Espesor 60 mm.	
			**U muro : 2,5 – 0,58** **U techo : 0,47 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

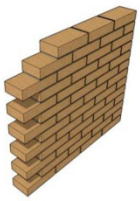
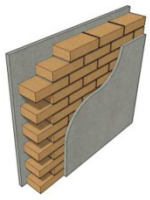
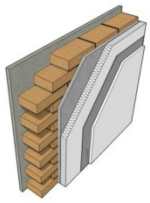
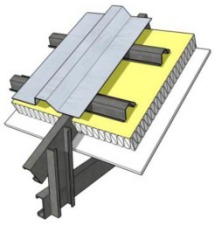
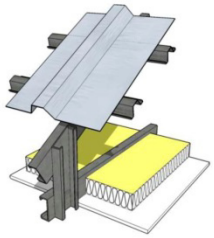
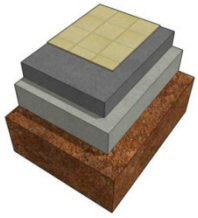
TIPOLOGÍA	Nº 1	CÓDIGO	VAL1P

Descripción	Vivienda de albañilería de ladrillo de un piso, pareada.

Superficie	66 m^2	Superficie envolvente	187 m^2	Superficie ventanas	15.7m^2	Volumen	138 m^3	Factor de Forma	1,36

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 14 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 2,5 - 0,6** **U techo : 0,84 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

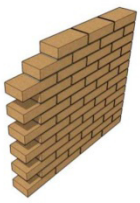
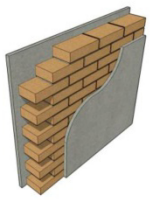
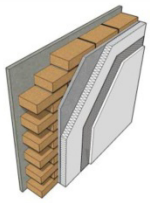
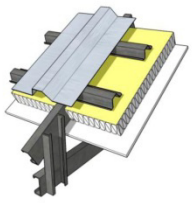
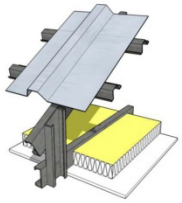
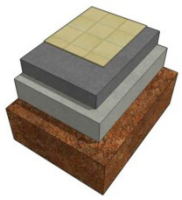
TIPOLOGÍA	Nº 2	CÓDIGO	VAL2P

Descripción	Vivienda de albañilería de ladrillo de dos pisos, pareada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 14 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 2,5 - 1,1** **U techo : 0,84 - 0,38** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

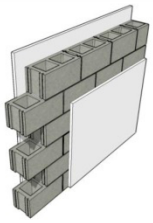
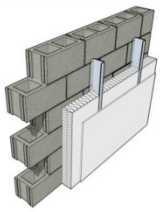
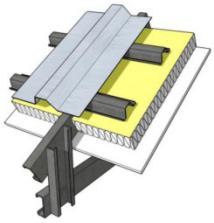
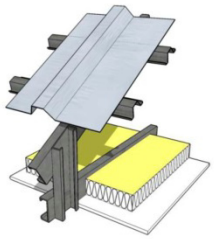
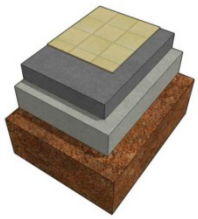
TIPOLOGÍA	Nº 4	CÓDIGO	VBC1P

Descripción	Vivienda de bloque de cemento de un piso, pareada.

Superficie	50 m^2	Superficie envolvente	166 m^2	Superficie ventanas	4,6 m^2	Volumen	105 m^3	Factor de Forma	1,6

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 19 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

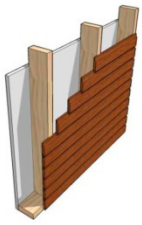
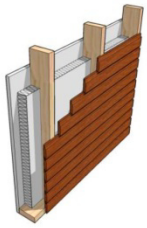
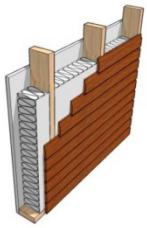
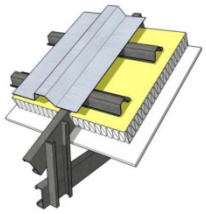
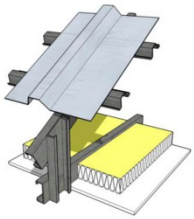
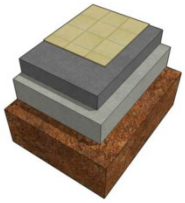
TIPOLOGÍA	Nº 5	CÓDIGO	VM2P

Descripción	Vivienda de madera de dos pisos, pareada.

Superficie	80 m^2	Superficie envolvente	196 m^2	Superficie ventanas	4,95 m^2	Volumen	172 m^3	Factor de Forma	1,13

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

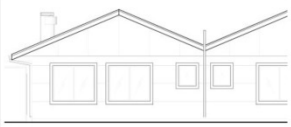
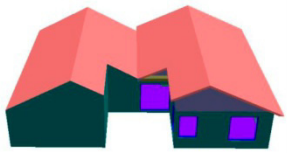
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 0 mm.	**Muro simple** Espesor 50 mm.	**Muro con refuerzo térmico** Espesor 60 mm.	
			**U muro : 2,5 – 0,58** **U techo : 0,47 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

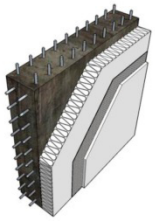
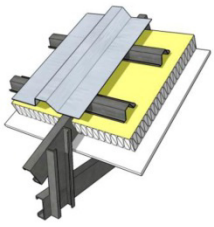
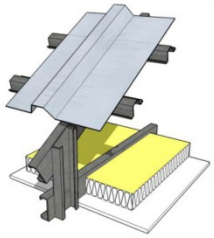
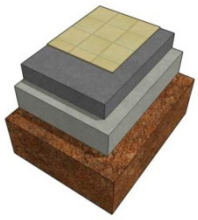
TIPOLOGÍA	Nº 1	CÓDIGO	VH1P

Descripción	Vivienda de hormigón armado de un piso, pareada.

Superficie	66 m^2	Superficie envolvente	187 m^2	Superficie ventanas	15.7m^2	Volumen	138 m^3	Factor de Forma	1,36

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

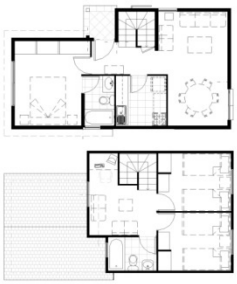
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 20 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,7** **U techo : : 0,84 - 0,38** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

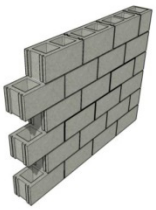
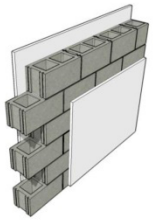
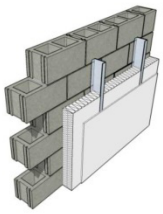
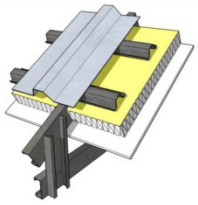
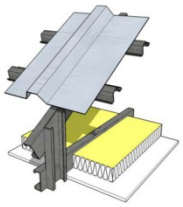
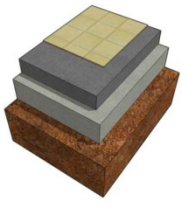
TIPOLOGÍA	Nº 2	CÓDIGO	VBC2A

Descripción	Vivienda de bloque de cemento de dos pisos, aislada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

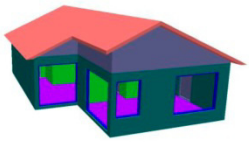
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 19 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

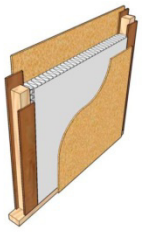
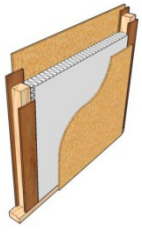
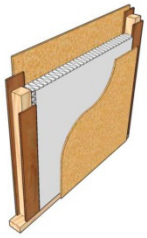
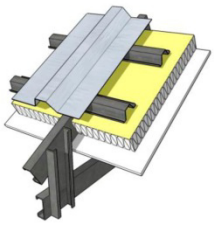
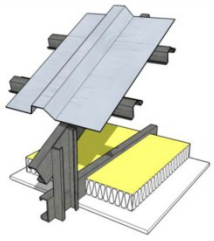
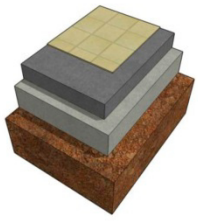
TIPOLOGÍA	Nº 1	CÓDIGO	VPS1A

Descripción	Vivienda en panel sip de un piso, aislada.

Superficie	66 m^2	Superficie envolvente	187 m^2	Superficie ventanas	15.7m^2	Volumen	138 m^3	Factor de Forma	1,36

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

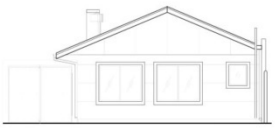
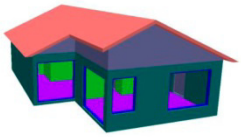
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro Aislación 0-11 mm.	**Muro** Aislación 14-31 mm.	**Muro** Aislación 59 mm.	
			**U muro : 3- 0,6** **U techo : 0,84 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

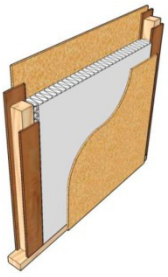
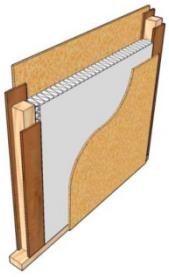
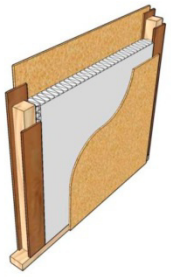
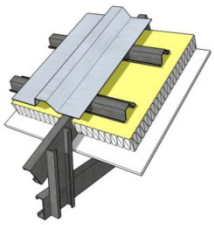
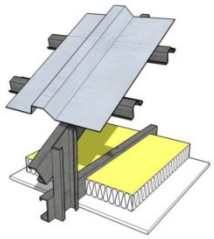
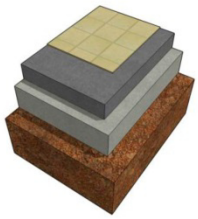
TIPOLOGÍA	Nº 1	CÓDIGO	VPS1A(t16)

Descripción	Vivienda en panel sip de un piso, aislada.

Superficie	66 m^2	Superficie envolvente	187 m^2	Superficie ventanas	15.7m^2	Volumen	138 m^3	Factor de Forma	1,36

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro Aislación 0-11 mm.	**Muro** Aislación 14-31 mm.	**Muro** Aislación 59 mm.	
			**U muro :3- 0,6** **U techo : 0,84 - 0,25** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

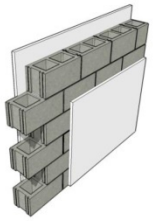
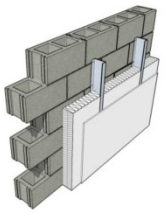
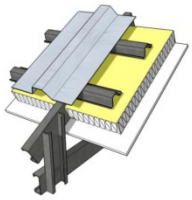
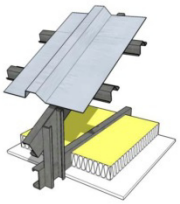
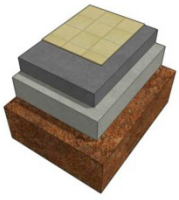
TIPOLOGÍA	Nº 2	CÓDIGO	VBC2P

Descripción	Vivienda de albañilería de ladrillo de dos pisos, pareada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 19 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro : 3- 1,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

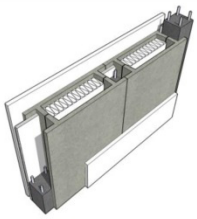
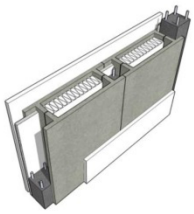
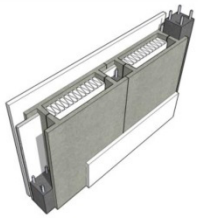
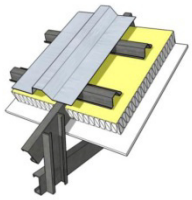
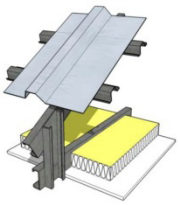
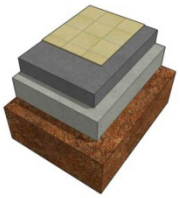
TIPOLOGÍA	Nº 2	CÓDIGO	VFC2P

Descripción	Vivienda de ferrocemento de dos pisos, pareada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

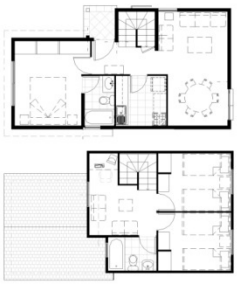
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro Aislación 0-11 mm.	**Muro** Aislación 25 mm.	**Muro** Aislación 55 mm.	
			**U muro : 3- 0,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

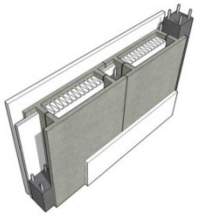
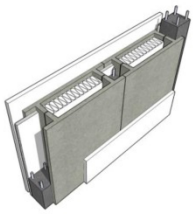
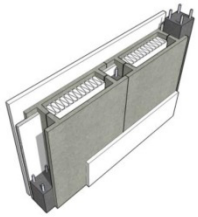
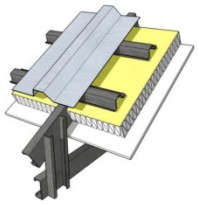
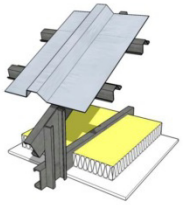
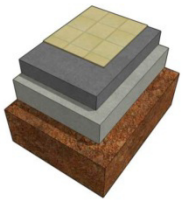
TIPOLOGÍA	Nº 2	CÓDIGO	VBC2A

Descripción	Vivienda de ferrocemento de dos pisos, aislada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro Aislación 0-11 mm.	**Muro** Aislación 25 mm.	**Muro** Aislación 55 mm.	
			**U muro : 3- 0,6** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

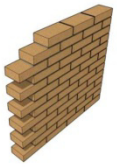
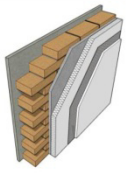
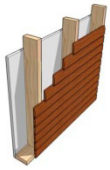
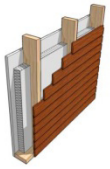
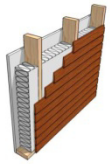
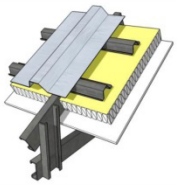
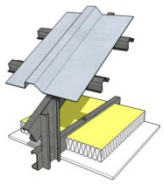
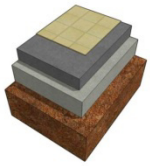
TIPOLOGÍA	Nº 2	CÓDIGO	VALM2A

Descripción	Vivienda de albañilería de ladrillos y madera de dos pisos, aislada.

Superficie	75 m^2	Superficie envolvente	212 m^2	Superficie ventanas	6.05 m^2	Volumen	171 m^3	Factor de Forma	1,24

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

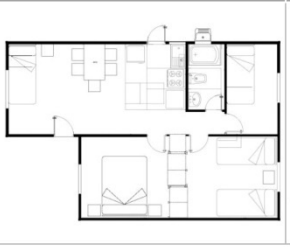
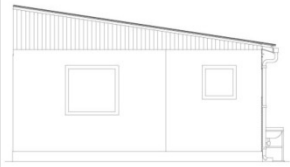
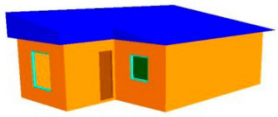
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 14 mm.	**Muro estucado** Mortero cemento Espesor 25 mm.	**Muro con refuerzo térmico** EIFS	
			**U muro AL : 2,5 - 0,6** **U muro M : 2,5 – 0,58** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Muro simple Espesor 0 mm.	**Muro simple** Espesor 50 mm.	**Muro con refuerzo térmico** Espesor 60 mm.	
			
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

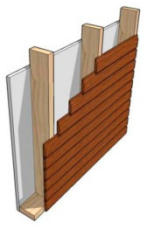
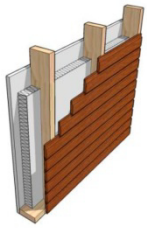
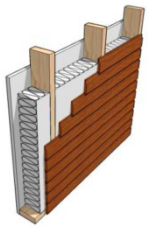
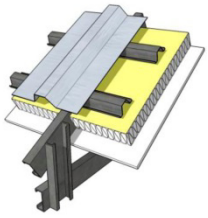
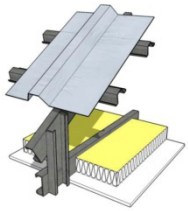
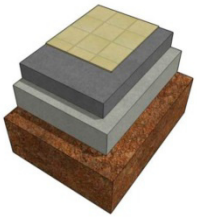
TIPOLOGÍA	Nº 4	CÓDIGO	VM1A

Descripción	Vivienda de madera de un piso, aislada.

Superficie	50 m^2	Superficie envolvente	166 m^2	Superficie ventanas	4,6 m^2	Volumen	105 m^3	Factor de Forma	1,6

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

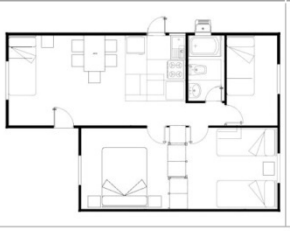
			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 0 mm.	**Muro simple** Espesor 50 mm.	**Muro con refuerzo térmico** Espesor 60 mm.	
			**U muro : 2,5 – 0,58** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

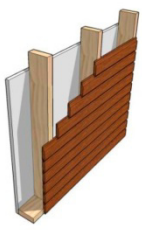
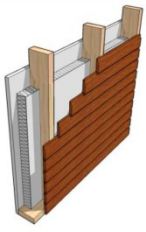
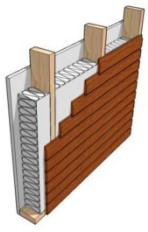
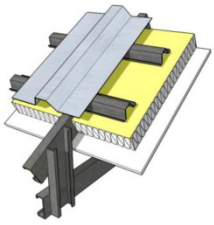
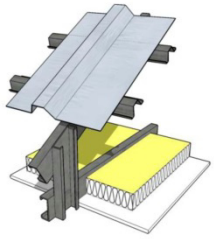
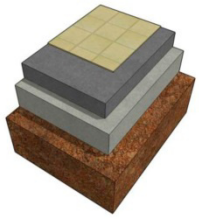
TIPOLOGÍA	Nº 4	CÓDIGO	VM1P

Descripción	Vivienda de madera de un piso, pareada.

Superficie	50 m^2	Superficie envolvente	166 m^2	Superficie ventanas	4,6 m^2	Volumen	105 m^3	Factor de Forma	1,6

PLANTA	ELEVACIÓN	3D
		

PRINCIPALES CONFIGURACIONES DE ENVOLVENTES

			RANGO PROPIEDADES TÉRMICAS U (W/m^2K)
			
Muro simple Espesor 0 mm.	**Muro simple** Espesor 50 mm.	**Muro con refuerzo térmico** Espesor 60 mm.	
			**U muro : 2,5 – 0,58** **U techo : : 0,84 - 0,33** **U piso : 1,5**
Techumbre Aislación bajo costaneras	**Techumbre** Aislación sobre cielo	**Piso simple**	

Fuente: Elaboración propia con datos del INE

Anexo 3: Parámetros térmicos optimizados de referencia del parque de construcciones habitacionales del año 2011 por zona climática (NCh 1079)

A continuación se presentan los valores límites de Transmitancia Térmica, Factores Solares de Vanos y porcentaje de superficie acristalada máxima por zona climática.

a) Zona Climática 1 NL: Zona Norte Litoral

ZONA CLIMÁTICA 1 : NORTE LITORAL (NL)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U (W/ m² K)**
Transmitancia límite de muro de fachada	2,0
Transmitancia límite de cerramiento en contacto con terreno	2,0
Transmitancia límite de cubierta	0,8
Transmitancia límite de suelos en contacto con el terreno	2,0
Transmitancia límite de pisos ventilados	3,0
Transmitancia límite de puente térmico	3,3
Transmitancia ponderada límite paramentos verticales	5,0
Factor solar modificado límite de lucernarios	0,1

TRANSMITANCIA LÍMITE DE VANOS U (W/ m² K)				
% Vanos	**N**	**E/O**	**S**	**NE/NO**
0 a 10	5,70	5,70	5,70	5,70
11 a 20	5,70	5,70	5,30	5,70
21 a 30	5,70	5,20	5,00	5,70
31 a 40	5,60	5,00	4,80	5,60
41 a 50	5,50	4,50	4,70	5,50
51 a 60	5,20	4,30	4,50	5,20
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos (s/d)			
% Vanos	**Baja Carga Interna y Alta Carga Interna**		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a 20	-	-	-
21 a 30	0,54	-	-
31 a 40	0,50	-	0,56
41 a 50	0,45	0,60	0,49
51 a 60	0,40	0,54	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

b) Zona Climática 2 ND: Zona Norte Desértica

ZONA CLIMÁTICA 2 : NORTE DESÉRTICA (ND)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U (W/ m² K)**
Transmitancia límite de muro de fachada	0,5
Transmitancia límite de cerramiento en contacto con terreno	0,5
Transmitancia límite de cubierta	0,4
Transmitancia límite de suelos en contacto con el terreno	0,5
Transmitancia límite de pisos ventilados	0,7
Transmitancia límite de puente térmico	1,0
Transmitancia ponderada límite paramentos verticales	1,7
Factor solar modificado límite de lucernarios	0,3

TRANSMITANCIA LÍMITE DE VANOS U (W/ m² K)				
% Vanos	**N**	**E/O**	**S**	**NE/NO**
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	**Baja Carga Interna y Alta Carga Interna**		
	E / O	**N**	**NE / NO**
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	0,54	-	-
31 a 40	0,50		0,56
41 a 50	0,45	0,55	0,49
51 a 60	0,40	0,50	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

c) Zona Climática 3 VT: Zona Norte Valles Transversales

ZONA CLIMÁTICA 3 : NORTE VALLES TRANSVERSALES (NVT)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U (W/ m² K)**
Transmitancia límite de muro de fachada	0,8
Transmitancia límite de cerramiento en contacto con terreno	0,8
Transmitancia límite de cubierta	0,6
Transmitancia límite de suelos en contacto con el terreno	0,8
Transmitancia límite de pisos ventilados	1,2
Transmitancia límite de puente térmico	1,3
Transmitancia ponderada límite paramentos verticales	2,3
Factor solar modificado límite de lucernarios	0,38

TRANSMITANCIA LÍMITE DE VANOS U (W/ m² K)				
% Huecos	**N**	**E/O**	**S**	**NE/NO**
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	**Baja Carga Interna y Alta Carga Interna**		
	E / O	**N**	**NE / NO**
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	0,54	-	-
31 a 40	0,50	-	0,56
41 a 50	0,45	0,60	0,49
51 a 60	0,40	0,54	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

d) Zona Climática 4 CL: Zona Central Litoral

ZONA CLIMÁTICA 4 : CENTRAL LITORAL (CL)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U(W/ m² K)**
Transmitancia límite de muro de fachada	0,8
Transmitancia límite de cerramiento en contacto con terreno	0,8
Transmitancia límite de cubierta	0,6
Transmitancia límite de suelos en contacto con el terreno	0,8
Transmitancia límite de pisos ventilados	1,2
Transmitancia límite de puente térmico	1,3
Transmitancia ponderada límite paramentos verticales	2,3
Factor solar modificado límite de lucernarios	0,38

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Vanos	**N**	**E/O**	**S**	**NE/NO**
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	Baja Carga Interna y Alta Carga Interna		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	0,54	-	0,57
31 a 40	0,42	0,58	0,45
41 a 50	0,35	0,49	0,43
51 a 60	0,30	0,43	0,40
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

e) Zona Climática 5 CI: Zona Central Interior

ZONA CLIMÁTICA 5 : CENTRAL INTERIOR (CI)	
PARAMETROS CARACTERISTICOS MEDIOS	Valor U(W/ m² K)
Transmitancia límite de muro de fachada	0,6
Transmitancia límite de cerramiento en contacto con terreno	0,6
Transmitancia límite de cubierta	0,4
Transmitancia límite de suelos en contacto con el terreno	0,6
Transmitancia límite de pisos ventilados	0,8
Transmitancia límite de puente térmico	1,00
Transmitancia ponderada límite paramentos verticales	1,72
Factor solar modificado límite de lucernarios	0,29

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Huecos	N	E/O	S	NE/NO
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	Baja Carga Interna y Alta Carga Interna		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	0,54	-	-
31 a 40	0,50	0,60	0,56
41 a 50	0,45	0,55	0,49
51 a 60	0,40	0,50	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

f) Zona Climática 6 SL: Zona Sur Litoral

ZONA CLIMÁTICA 6 : SUR LITORAL (SL) (W/ m² K)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U**
Transmitancia límite de muro de fachada	0,6
Transmitancia límite de cerramiento en contacto con terreno	0,6
Transmitancia límite de cubierta	0,4
Transmitancia límite de suelos en contacto con el terreno	0,6
Transmitancia límite de pisos ventilados	0,8
Transmitancia límite de puente térmico	1,00
Transmitancia ponderada límite paramentos verticales	1,72
Factor solar modificado límite de lucernarios	0,29

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Vanos	**N**	**E/O**	**S**	**NE/NO**
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	**Baja Carga Interna y Alta Carga Interna**		
	E / O	**N**	**NE / NO**
0 a 10	-	-	-
11 a 20	-	-	-
21 a 30	0,54		0,57
31 a 40	0,42	0,58	0,45
41 a 50	0,35	0,49	0,37
51 a 60	0,30	0,43	0,32
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

g) Zona Climática 7 SI: Zona Sur Interior

ZONA CLIMÁTICA 7 : SUR INTERIOR (SI)	
PARAMETROS CARACTERISTICOS MEDIOS	**Valor U(W/ m² K)**
Transmitancia límite de muro de fachada	0,5
Transmitancia límite de cerramiento en contacto con terreno	0,5
Transmitancia límite de cubierta	0,3
Transmitancia límite de suelos en contacto con el terreno	0,5
Transmitancia límite de pisos ventilados	0,7
Transmitancia límite de puente térmico	0,95
Transmitancia ponderada límite paramentos verticales	1,43
Factor solar modificado límite de lucernarios	0,36

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Vanos	N	E/O	S	NE/NO
0 a 10	3,10	3,10	3,10	3,10
11 a20	3,10	3,10	3,10	3,10
21 a 30	3,10	3,00	2,60	3,10
31 a 40	3,10	2,70	2,20	3,10
41 a 50	3,10	2,40	2,00	3,10
51 a 60	3,00	2,30	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	Baja Carga Interna y Alta Carga Interna		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	-	-	-
31 a 40	0,54	0,60	0,56
41 a 50	0,45	0,56	0,49
51 a 60	0,40	0,54	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

h) Zona Climática 8 SE: Zona Sur Extremo

ZONA CLIMÁTICA 8 : SUR EXTREMO (SE)	
PARAMETROS CARACTERISTICOS MEDIOS	Valor U(W/ m² K)
Transmitancia límite de muro de fachada	0,4
Transmitancia límite de cerramiento en contacto con terreno	0,4
Transmitancia límite de cubierta	0,25
Transmitancia límite de suelos en contacto con el terreno	0,4
Transmitancia límite de pisos ventilados	0,5
Transmitancia límite de puente térmico	0,7
Transmitancia ponderada límite paramentos verticales	1,15
Factor solar modificado límite de lucernarios	0,2

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Vanos	N	E/O	S	NE/NO
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,40	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	Baja Carga Interna y Alta Carga Interna		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	-	-	-
31 a 40	0,54		0,56
41 a 50	0,45	0,60	0,49
51 a 60	0,40	0,54	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

Zona Climática 9 AN: Zona Andina

ZONA CLIMÁTICA 9 : ANDINA (An)	
PARAMETROS CARACTERISTICOS MEDIOS	Valor U(W/ m² K)
Transmitancia límite de muro de fachada	0,3
Transmitancia límite de cerramiento en contacto con terreno	0,3
Transmitancia límite de cubierta	0,25
Transmitancia límite de suelos en contacto con el terreno	0,3
Transmitancia límite de pisos ventilados	0,4
Transmitancia límite de puente térmico	0,5
Transmitancia ponderada límite paramentos verticales	0,87
Factor solar modificado límite de lucernarios	0,15

TRANSMITANCIA LÍMITE DE VANOS U(W/ m² K)				
% Vanos	N	E/O	S	NE/NO
0 a 10	3,50	3,50	3,50	3,50
11 a20	3,50	3,50	3,00	3,50
21 a 30	3,50	2,90	2,50	3,50
31 a 40	3,40	2,60	2,20	3,40
41 a 50	3,20	2,50	2,10	3,20
51 a 60	3,00	2,40	1,90	3,00
> 60	Deberá cumplir con las exigencias de Eficiencia Energética			

Factor Solar Modificado Límite de Vanos(s/d)			
% Vanos	Baja Carga Interna y Alta Carga Interna		
	E / O	N	NE / NO
0 a 10	-	-	-
11 a20	-	-	-
21 a 30	-	-	-
31 a 40	0,54	0,54	0,56
41 a 50	0,45	0,49	0,49
51 a 60	0,40	0,43	0,43
> 60	Deberá cumplir con las exigencias de Eficiencia Energética		

Anexo 4 : Infiltración de aire normalizadas por tipología de construcciones presentes en las 54 capitales provinciales del país e infiltración ponderada provincial (Referencia parque construcciones inscritos año 2011)

	T1: VAL1A	T2: VAL1P	T3: VAL2A	T4: VAL2P	T5: VH1A	T6: VH2A	T7: VDHYL	T8: VBC1A	T9:VBC2A	T10:VBC2P	T11: VM1A	T12:VM1P	T13:VM2A	T14:VM2P	T15:VPS1A	16:VFC1A	17:VFC2A	T18:VFC2P	T19:VALM2A = T3	T20:VALM2P = T4	infiltración normalizada ponderada
Arica				1,03			1,93														1,3
Putre (año 2008)								1,47													1,5
Iquique							1,31			0,95											1,2
Pozo Almonte	1,70							1,48													1,5
Tocopilla									0,94												0,9
Calama			1,74			1,82	3,27														2,8
Antofagasta						1,12	1,99														1,9
Chañaral								1,00	1,55												1,0
Copiapó			1,09				2,02														1,7
Vallenar	0,44		0,53				0,92	0,38													0,7
Coquimbo	0,91		0,95		0,67		1,76						1,85								1,4
Ovalle	1,41	1,61																			1,5
Illapel	0,62	0,88	0,69								1,06								0,69		0,7
La Ligua	0,65					0,75	1,29				1,10		1,38								1,1
Los Andes	1,14	1,60	1,17				2,17														1,9
San Felipe	1,16	1,63	1,18	1,18	0,86		2,20														1,3
Quillota	0,66	0,93	0,73	0,73			1,31				1,12			1,41							0,9
Valparaíso			1,29				2,41												1,29		2,2
San Antonio	1,16						2,22				1,97		2,31				1,45		1,2		2,1
Hanga Roa								0,84			1,63				0,50	0,50					1,0
Quilpué	1,16	1,64	1,19	1,19		1,24	2,22												1,2	1,19	1,5
Colina	0,69		0,75	0,75		0,79			1,01				1,46								0,9
Santiago			0,88			0,92	1,62														1,5
Puente Alto			0,87	0,87		0,91														0,87	0,8
San Bernardo	0,82		0,87	0,87					1,17										0,87		0,9
Melipilla	0,69		0,75				1,36				1,17				0,36	0,36					0,9

	T1: VAL1A	T2: VAL1P	T3: VAL2A	T4: VAL2P	T5: VH1A	T6: VH2A	T7: VDHYL	T8: VBC1A	T9:VBC2A	T10:VBC2P	T11: VM1A	T12:VM1P	T13:VM2A	T14:VM2P	T15:VPS1A	16:VFC1A	17:VFC2A	T18:VFC2P	T19:VALM2A = T3	T20:VALM2P = T4	infiltración normalizada ponderada
Talagante	0,82	1,16	0,87	0,87		0,91			1,17											0,87	1,1
Rancagua	0,76	0,76	1,00																1,00	1,28	0,9
San Fernando	0,85			1,16							0,98						0,94		1,1		0,9
Pichilemu	1,07										1,07		1,06		0,60						1,0
Curicó	1,02	1,02		1,09						1,08	1,02										1,0
Talca	1,10			1,06			1,17												1,1		1,1
Linares	0,79	0,12									1,34			1,65					0,9	0,85	0,7
Cauquenes	1,41	1,98		1,42						1,90			2,76						1,4	1,42	1,6
Chillán	0,77			0,84							1,31		1,62	1,62					0,8	0,84	1,3
Los Ángeles											1,13		1,43	1,43					0,7	0,47	1,2
Concepción			1,40			1,46	2,61				2,33		2,71				1,17		1,40		1,7
Lebu											2,42		2,81	2,81					1,5		2,3
Angol	0,66										1,13	1,59	1,43								1,2
Temuco							1,12	0,46			0,90		1,25						0,6		0,8
Valdivia							1,13				0,91		1,26		0,28						1,0
La Unión							1,13				0,91		1,25								1,0
Osorno			0,66								0,93		1,29								1,1
Puerto Montt			1,10				2,01				1,76		2,12		0,54	0,54	1,29				1,3
Castro											1,08		1,38								1,2
Chaitén											1,00		1,00								1,0
Coyhaique											1,94			2,33	0,59	0,59	1,42	0,67			1,5
Puerto Aysén											1,78		2,16					0,62			1,6
Chile Chico	1,97										3,31										2,9
Cochrane											2,37		2,79								2,7
Puerto Natales											1,41	1,99	1,81								1,7
Punta Arenas											2,86	4,03	3,34	3,34			2,10	0,96			2,8
Porvenir	0,64										1,41		1,81								1,2
Puerto Williams														2,56			1,57				2,1

Anexo 5: Sistemas constructivos tradicionales y nuevos más utilizados para edificar viviendas en Chile

SISTEMA CONSTRUCTIVO FERROCEMENTO

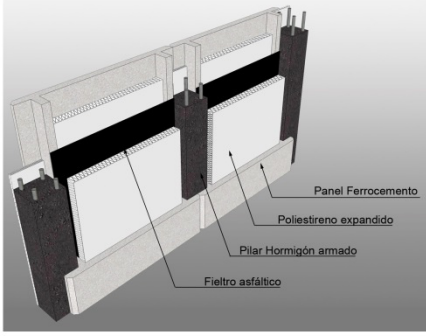
DESCRIPCIÓN DEL SISTEMA

Sistema basado en el uso de paneles estandarizados de micro hormigón de cemento armado laminar. Una forma especial de hormigón armado confeccionado con mortero de cemento en delgadas láminas de 2,5 cm de espesor y refuerzos metálicos. El refuerzo consiste en una malla de acero electro soldada de pequeño diámetro como armadura difusa más una malla de alambre flexible como armadura discreta en algunos casos. Los muros interiores y exteriores se forman utilizando dos láminas nervadas de ferrocemento colocadas frente a frente, permitiendo que las nervaduras configuren un pilar de unión, que se llena con un hormigón de alta fluidez, y una cámara de aire donde se dispone material de refuerzo térmico o acústico en espesor variable según necesidades de protección. Es posible además configurar losetas prefabricadas del mismo material con sobre losa armada si fuese necesario.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Viviendas sociales, viviendas de medio y alto estandar, edificacion de mediana altura, colegios, oficinas, y diferentes proyectos que se generan como resultado de la industrialización.	Universidad del Bío-Bío Cementos Bío-Bío	No Tradicional	Citec UBB

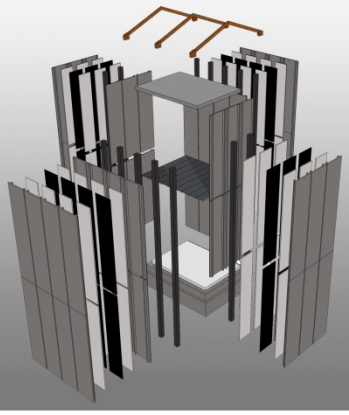
INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL



- **Aislación térmica muros:** 0,50 – 1,50 W/m² K
- **Permeabilidad al aire envolvente:** 4,0 – 8,0 1/h a 50 Pa.
- **Estanqueidad al agua de fachada:** ≥ 1000 Pa
- **Aislación acústica**
  Ruido aéreo fachada: Sin registro
  Ruido de impacto: Sin registro
- **Resistencia al fuego:**
  Muro: ≥ F90
  Tabique: ≥ F15
  Techumbre: ≥ F60
  Losa: ≥ F120
- **Prestaciones estructurales (1 lámina de ferrocemento de 0,5x2,25x0,03m)**
  Compresión vertical
  Carga de rotura: ≥ 8000 Kg/m
  Carga en límite proporcional: ≥ 4000 Kg/m
  Deformación admisible: 7,5 mm.
  Flexión
  Carga de rotura: 514 Kg/m
  Carga en el límite de proporcionalidad: 250 Kg/m
  Deformación admisible: 100 mm
  Impacto
  Panel doble sin deterioro con energía de impacto ≥ 250 J

EXPLOTADO



MONTAJE



01 Colocación de los paneles sobre una fundacion típica de Hormigón armado y radier según cálculo. Los paneles se afianzan uno al lado de otro a través de amarres de acero y pilares de hormigón armado según cálculo.

02 Colocación de losetas sobre paneles nivel 1. Hormigonado de viga de amarre perimetral de primer nivel y sobre losa de ser necesario. Continuación de estructura nivel 1 para posterior colocación de paneles en nivel 2.

03 Colocación de viga de amarre perimetral de hormigón armado, para luego colocar cerchas de madera que se incorporan a la estructura mediante esparragos de acero.

IMAGENES PROYECTOS



Proyecto FDI, UBB, 2000, viviendas ferrocemento, Concepción VIII Región

Casa Llaima, Cementos Bío-Bío 2003 Santiago, Region metropolitana

Proyecto Reconstruccion Post terremoto 2010, Talca, VII Región

Fuente: Elaboración propia

SISTEMA CONSTRUCTIVO SIP

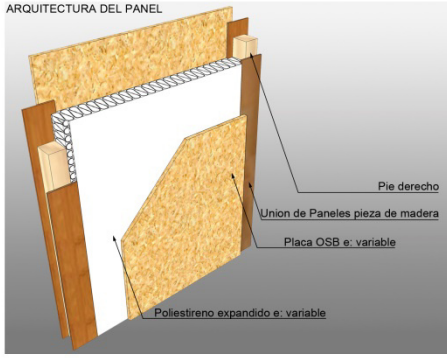
DESCRIPCIÓN DEL SISTEMA

Structural insulated panel (SIP) Sistema de paneles de madera estandarizados e industrializados en base placas de OSB (oriented strand board). Esta placa confiere la capacidad estructural mecánica del panel, y además es el soporte de la aislación interior en base a Poliestireno expandido de densidad media aparente (entre 15kg m2 y 20 kg/m2) y con de espesor variable, según las solicitaciones de cada proyecto y la zonificación climática. Los muros exteriores o estructurales se forman utilizando elementos de madera lineales (pie derechos) y lenguetas que permiten la unión entre paneles, para conformar un elemento monolítico y continuo.
Para las losas, se usan espesores de aislación mayores. La unión entre ellos se hace a través de elementos de madera mas lenguetas asegurando su buen comportamiento. Los paneles de losa pueden ir colocados directamente sobre los muros, afianzados a través de clavos o tornillos, o sobre una estructura de vigas de entre piso. Los paneles de techumbre se colocan sobre cerchas traslapados unos de otros. El sistema de unión entre paneles se realiza también con pies derechos y lenguetas.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Soluciones habitacionales, equipamiento comunitario como colegios, postas, retenes, sedes sociales, oficinas, galpones, etc	Termocret Tecnopanel The Wall Construhome etc.	No Tradicional	Idiem, Dictuc

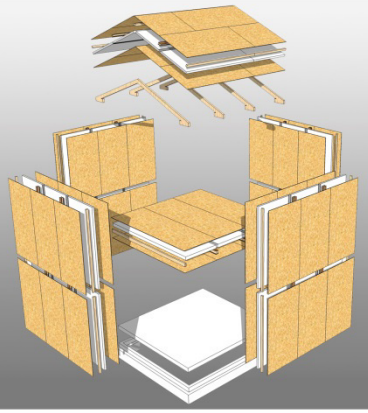
INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL

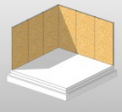


- **Aislación térmica muros:** 0,57 - 0,19 W/m² K
- **Permeabilidad al aire envolvente:** Sin Registro
- **Estanqueidad al agua de fachada:** Sin Registro
- **Aislación acústica**
  Ruido aéreo fachada: 37-47 db
  Ruido de impacto: Sin Registro
- **Resistencia al fuego:**
  Muro: ≥ F15
  Tabique: ≥ F15
  Techumbre: ≥ F15
  Losa: ≥ F15
- **Prestaciones estructurales (1 placa de Panel SIP 2,44x1,22x0,084 m)**
  Compresión vertical
  Carga de rotura: ≥ 12200 Kg/m
  Carga en límite proporcional: ≥ 7200 Kg/m
  Deformación admisible: 1.4 mm.
  Flexión
  Carga de rotura: 800 Kg/m
  Carga en el límite de proporcionalidad: 545 Kg/m
  Deformación admisible: 16 mm
  Impacto
  Panel sin deterioro con energía de impacto ≥ 350 J

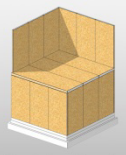
EXPLOTADO



MONTAJE



01 Colocación de los paneles sobre una solera inferior amarrada a una fundación típica de Hormigón armado y radier según cálculo. Los paneles se afianzan uno al lado de otro a través de lenguetas y pie derechos.



02 Colocación de paneles de losa sobre paneles nivel 1 afianzada a través de clavos o tornillos
A continuación se realiza la colocación de paneles en nivel 2 puestas sobre una solera de nivelación.



03 Colocación paneles de nivel 2. A continuación se ubican cerchas sobre las cuales se colocan paneles de techo desfasados entre si y afianzados mediante lenguetas y piezas de madera.

IMAGENES PROYECTOS



450 viviendas Padre las casas, Temuco, IX Región



Oficinas Ecopelet, 2007 Santiago, Región Metropolitana



Hogar de ancianos Alhue, 2010 Melipilla, Región Metropolitana



Casa en panel SIp, 2011, Valparaiso, V Región

Fuente: Elaboración propia

SISTEMA CONSTRUCTIVO ACERO GALVANIZADO

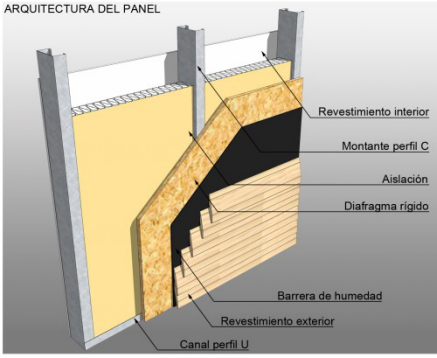
DESCRIPCIÓN DEL SISTEMA

Sistema constructivo totalmente en seco, en el cual los muros perimetrales,tabiques, entrepisos, cielos y techos, son soportados por una estructura de perfiles de acero galvanizado.Los perfiles que componen el sistema son los montantes o pie derechos, soleras, atiesadores, diagonales o tirantes, perfiles soportantes para cielos. Todos los elementos son afianzados mediantes tornillos autoperforantes de acero. Los espacios libres dejados por los montantes son aprovechados para incorporar aislación térmica/acústica de diferentes densidades.
Los tabiques o muros se configuran por medio de montantes, dispuestos cada 40 a 60 dependiente de la superficie del panel y de soleras o perfil U colocados horizontalmente como soporte de los perfiles U, los cuales se arriostran mediantes diagonales del mismo material. Las losas se conforman a través de vigas perimetrales compuestas (ejemplo dos perfiles canales o montantes) a las cuales se les incorporan las vigas maestras de pisos. Para mejorar las prestaciones acústicas y térmicas de esta, a la estructura de acero galvanizado es posible incorporarle una loseta de hormigón liviano.Para la estructura de techumbre, se utilizan perfiles c y u, dependiendo de su diseño y se le añade la utilización de diagonales o riostras. Este sistema idealmente es afianzado mediante placas de OSB (Oriented Strand Board), para entregar rigidez y como revestimiento es utilizado usualmente el yeso cartón como buen retardante al fuego, también la madera, fibrocemento, etc.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Soluciones habitacionales, soluciones de estructuras complementarias como cielos y tabiquerías de zonas secas y húmedas en diversos equipamientos e infraestructuras	Knauf Cintac Formac Perfimet Metalcom etc.	Tradicional	-

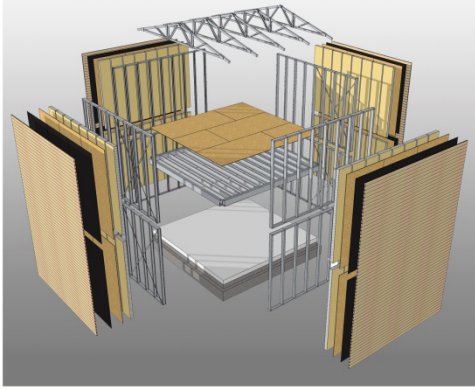
INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL



- **Aislación térmica muros:** 0,76 - 0,55 W/m² K
- **Permeabilidad al aire envolvente:** Sin registro
- **Estanqueidad al agua de fachada:** Sin registro
- **Aislación acústica**
  Ruido aéreo fachada: Sin registro
  Ruido de impacto: Sin registro
- **Resistencia al fuego:**
  Muro: ≥ F90
  Tabique: ≥ F15
  Techumbre: ≥ F60
  Losa: No registra
- **Prestaciones estructurales**
  Compresión vertical
  Carga de rotura: Sin registro
  Carga en límite proporcional: Sin registro
  Deformación admisible: Sin registro
  Flexión
  Carga de rotura: Sin registro
  Carga en el límite de proporcionalidad: Sin registro
  Deformación admisible: Sin registro
  Impacto
  Panel sin deterioro con energía de impacto : Sin registro

EXPLOTADO



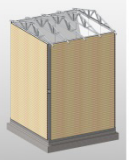
MONTAJE



01 Colocación de los montantes sobre un perfil canal inferior amarrada a una fundacion tipica de Hormigón armado y radier según cálculo. Los montantes se atornillan cada 40 a 60 cm distanciados unos de otros. Entre montantes se coloca lana mineral y se atornillan placas OSB.

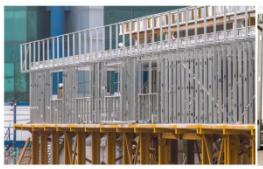


02 Colocación de viga de amarre perimetral según cálculo. A ellas se afianza la estructura de piso de metalcon. El envigado estructural se termina con placas OSB, traslapadas entre si . Todos los espacios intermedios son rellenados con lana mineral .



03 Colocación paneles OSB de nivel 2. A continuación se colocan cerchas. Colocacion de elementos de terminación interior (yeso cartón o fibrocemento) y exterior (madera, fibrocemento, etc.).

IMAGENES PROYECTOS



Oficina Planta Formac,
Quilicura, Región Metropolitana



Conjunto Residencial Los Conquistadores I y II,
Puente Alto, Región Metropolitana

Fuente: Elaboración propia

SISTEMA CONSTRUCTIVO ENTRAMADO DE MADERA

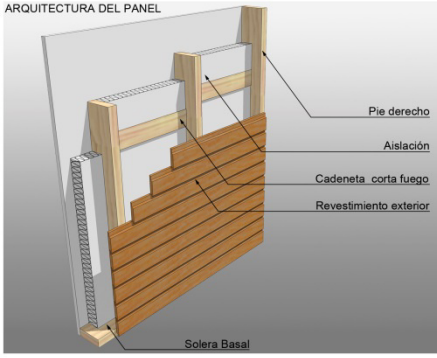
DESCRIPCIÓN DEL SISTEMA

Sistema que utiliza la barra (pilar, poste, pie derecho, diagonal, solera, etc.) como elemento básico del sistema. Dependiendo de las maneras de transmitir las cargas al suelo de fundación, que tienen estos sistemas, se distinguen: a) Sistemas de paneles portantes, en los que las cargas son transmitidas a los cimientos por paneles y b) Sistema de vigas y soporte verticales, en los que las cargas de techumbre y entre pisos son recibidas por vigas que las trasladan a los apoyos, y estos a sus vez a los cimientos.
Para la conformación de tabiques se utilizan pie derechos, unidos por soleras en su parte superior e inferior, y distanciado entre 40 y 60 cm según el cálculo. El espacio disponible entre pies derechos es ocupado para colocar corta fuegos o cadenetas (que evitan el paso del fuego de un compartimento a otros) y la aislación del tipo térmica y acústica. En cuando a las losas, se conforman mediante vigas principales y secundarias según calculo. Los elementos de techumbre se conforman en base a tijerales (no estructurales) o cerchas (estructurales), colocados uniformemente y apoyados sobre muros o tabiques estructurales.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Soluciones habitacionales en general de hasta dos pisos con mansarda, equipamiento comunitario como colegios, postas, retenes, oficinas, sedes sociales, viviendas sociales, ampliaciones, edificios en general hasta dos pisos, etc.	Corporación de la madera (CORMA) Instituto Forestal (INFOR) Aserraderos Arauco S.A. Aserraderos Cementos Bío-Bío Aserraderos Paillaco S.A. CMPC S.A., Maderera Río Itata S. A., etc.	Tradicional	-

INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL

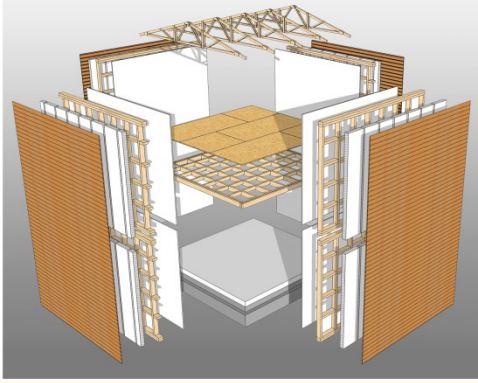


- **Aislación térmica muros:** 0,76 - 0,55 W/m² K

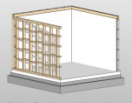
Permeabilidad al aire envolvente: Sin registro

- **Estanqueidad al agua de fachada:** Sin registro
- **Aislación acústica**
  Ruido aéreo fachada: Sin registro
  Ruido de impacto: Sin registro
- **Resistencia al fuego:**
  Muro: ≥ F90
  Tabique: ≥ F15
  Techumbre: ≥ F60
  Losa: No registra
- **Prestaciones estructurales**
  Compresión vertical
  Carga de rotura: Sin registro
  Carga en límite proporcional: Sin registro
  Deformación admisible: Sin registro
  Flexión
  Carga de rotura: Sin registro
  Carga en el límite de proporcionalidad: Sin registro
  Deformación admisible: Sin registro
  Impacto
  Panel sin deterioro con energía de impacto : Sin registro

EXPLOTADO



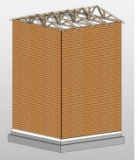
MONTAJE



01 Colocación de pie derechos sobre soleras para conformar paneles. Se incorporan retardantes al fuego horizontales (cadenetas) y un sistema de arriostramiento en base a Paneles OSB. El interior es revestido con un yeso cartón o similar.



02 Colocación de soleras de amarre perimetral, sobre las cuales se colocan la nueva linea de paneles que conforman el segundo nivel. Ademas se colocan vigas y viguetas de piuso formando cuadriculas y para arriostrar paneles OSB.



03 Colocación paneles arriostrantes, terminaciones muro interior y exterior en base a entablado u otro similar. El sistema se termina con una estructura de techumbre en base a cerchas de madera auto soportantes

IMAGENES PROYECTOS



Vivienda Unifamiliar En el Ramal, 2010,
Talca VII Región



Prototipo de Vivienda, 2010,
Traigén IX Región



Vivienda unifamiliar Lo Cañas, 2010,
La Florida, Región Metropolitana



Oficina Planta Formac,
Quilicura, Región Metropolitana

Fuente: Elaboración propia

SISTEMA CONSTRUCTIVO HORMIGÓN ARMADO

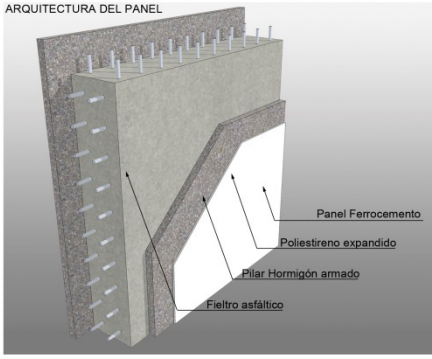
DESCRIPCIÓN DEL SISTEMA

Sistema basado en el uso de hormigón (cemento, ripios, áridos y agua), y una armadura de acero que consta de aceros redondos estriados, colocados como una retícula o entramado para soportar las cargas a tracción. Esta disposición se basa en que el acero trabaja bien a la tracción y el hormigón bien a la compresión. El sistema se conforma en base a muros, vigas, pilares y losas o en base a marcos rígidos de hormigón armado, elementos que pueden adaptar diversas formas arquitectónicas. Los muros son estucados o generalmente revestidos interior y exteriormente para conferir mejores terminaciones y en algunos casos mejorar la envolvente térmica. El hormigón es por lo general fabricado industrialmente y la confección de la armadura es realizada in situ. Sin embargo en la industria es posible encontrar los elementos estructurales pre-fabricados.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Soluciones habitacionales, equipamiento en general, edificación en altura, etc.	Cementos Bio-Bio Instituto del cemento y del hormigón Melon Polpaico Hormigón sustentable etc.	Tradicional	-

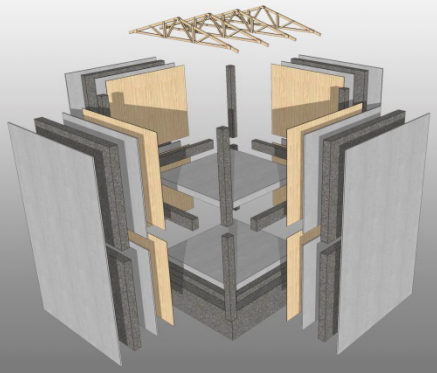
INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL

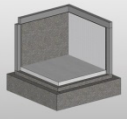


- **Aislación térmica muros:** 0,50 – 1,50 W/m² K
- **Permeabilidad al aire envolvente:** 4,0 – 8,0 1/h a 50 Pa.
- **Estanqueidad al agua de fachada:** ≥ 1000 Pa
- **Aislación acústica**
  Ruido aéreo fachada: Sin registro
  Ruido de impacto: Sin registro
- **Resistencia al fuego:**
  Muro: ≥ F90
  Tabique: ≥ F15
  Techumbre: ≥ F60
  Losa: ≥ F120
- **Prestaciones estructurales (1 lámina de ferrocemento de 0,5x2,25x0,03m)**
  Compresión vertical
  Carga de rotura: ≥ 8000 Kg/m
  Carga en límite proporcional: ≥ 4000 Kg/m
  Deformación admisible: 7,5 mm.
  Flexión
  Carga de rotura: 514 Kg/m
  Carga en el límite de proporcionalidad: 250 Kg/m
  Deformación admisible: 100 mm
  Impacto
  Panel doble sin deterioro con energía de impacto ≥ 250 J

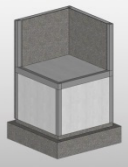
EXPLOTADO



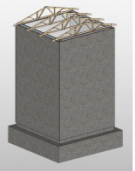
MONTAJE



01 Para fundaciones, y muros se realiza armado de enfierraduras y posterior colocación en obra según planos de cálculo. Colocación de moldajes para su posterior

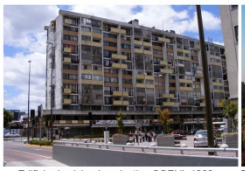


02 A los 28 días se realiza el desimbre de los elementos estructurales hormigonados, (muros, vigas y cadenas) para el armado de la enfierradura de la losa y posterior colocación de moldaje.



03 Fabricación de muros y elementos estructurales segundo nivel mas la colocación de cerchas de madera. Posterior al desimbre se realiza el estucado de todos los muros por ambos lados. Los muros pueden complementarse con aislación para cumplir los estandares térmicos según la zona climática.

IMAGENES PROYECTOS



Edificio de vivienda colectiva CORVI, 1963, Concepción, VIII Región



Edificio de vivienda colectiva Torres de Tajamar, 1967, Providencia Región Metropolitana



Conjunto Residencial Alto el Loa, 2007, Calama II Región



Edificio de vivienda colectiva Nuevo Centro, 2013, Talca, VII Región

Fuente: Elaboración propia

SISTEMA CONSTRUCTIVO ALBAÑILERIA CONFINADA

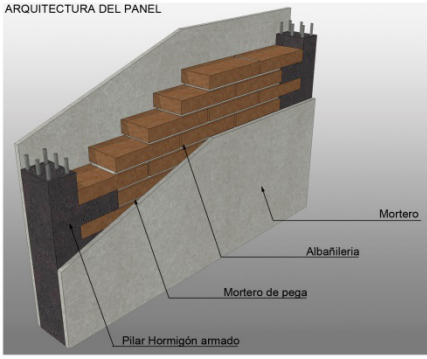
DESCRIPCIÓN DEL SISTEMA

Sistema basado en el uso de unidades de albañilería, en este caso ladrillo, confeccionado en base a arcillas cocidas a altas temperaturas y con un porcentaje de absorción de agua. Para conformar el sistema, los ladrillos se colocan en hiladas horizontales consecutivas y desfasadas entre si, adheridas a través de un mortero en base a cemento, áridos y agua. El refuerzo del sistema se hace a través de elementos de hormigón armado estructural (pilares, cadenas y vigas) colocados según calculo, para confinar los paños de albañilería, los cuales sólo resisten cargas verticales, por lo cual no es posible configurar losas en base a ladrillos. Los muros exteriores y tabiques son estucados en ambos lados con mortero de unos 2 a 4 cm de espesor.
El ladrillo es fabricado industrialmente y en serie, pero los muros son exclusivamente confeccionados en obra, por lo cual no permiten su prefabricación.

APLICACIONES	DESARROLLADORES/PROMOTORES	SISTEMA	CERTIFICACIÓN
Soluciones habitacionales, equipamiento comunitario como colegios, postas, retenes, oficinas, sedes sociales, bodegas, edificios en general hasta cuatro pisos, etc.	Cerámicas Rusticas Cauquenes Industrias Princesa Cerámica Santiago etc.	Tradicional	-

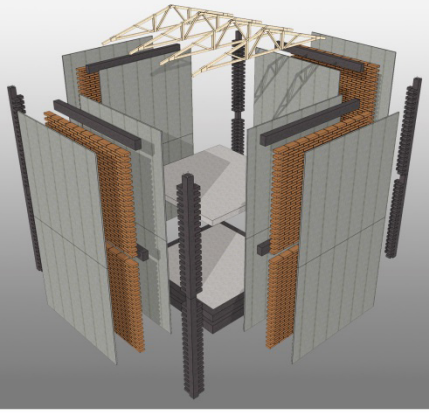
INFORMACION TÉCNICA

ARQUITECTURA DEL PANEL

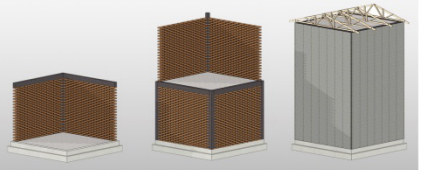


- **Aislación térmica muros:** 0,50 – 1,50 W/m² K
- **Permeabilidad al aire envolvente:** 4,0 – 8,0 1/h a 50 Pa.
- **Estanqueidad al agua de fachada:** ≥ 1000 Pa
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  Compresión vertical
  Carga de rotura: ≥ 8000 Kg/m
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  Deformación admisible: 7,5 mm.
  Flexión
  Carga de rotura: 514 Kg/m
  Carga en el límite de proporcionalidad: 250 Kg/m
  Deformación admisible: 100 mm
  Impacto
  Panel doble sin deterioro con energía de impacto ≥ 250 J

EXPLOTADO



MONTAJE



01 sobre las fundaciones se coloca la primera hilada de soga, la cual descansa sobre un mortero de nivelación. Las siguientes hiladas se van colocando unas sobre otra de forma consecutiva y desfasadas para trabar el muro. La union de dos muros muros paralelos o perpendiculares se realiza a traves de pilares de hormigón armado.

02 Colocacion de los muros primer nivel, los cuales se afianzan por medio de una cadena perimetral de hormigón armado. Sobre esta se configuran los muros del segundo nivel y la losa de hormigon armado que actua como diafragma rigido.

03 Colocacion de cadena perimetral en segundo piso, estuco de mortero en muros por ambos lados. Se colocan cerchas de madera u otro material espaciadas uniformemente

IMAGENES PROYECTOS



Conjunto Habitacional Terrazas Las Lomas, 2013, Concepción, VIII Región



Casa Quiñe, 2007 Miraflores, VII Región



Vivienda BMO, 2008, San Pedro de la Paz, VIII Región

Fuente: Elaboración propia

Anexo 6 **:** Proyectos investigación, desarrollo e innovación en ciencias y tecnologías de la construcción de viviendas en Chile periodo 1982-2012 (Líneas Conicyt, Fondecyt y Fondef y Corfo Innova)

6.1 Proyectos I + D Fondecyt

Ítem	Nombre Proyecto	Año		Código	Institución Responsable
1	Inspección de la construcción de obras de edificación	1986	1987	1860279	Pontificia Universidad Católica de Chile
2	Vivienda	1988	1989	1880336	Corporación de Promoción Universitaria
3	Comportamiento térmico de viviendas *	1989	1992	1890661	Universidad de Concepción
4	La calidad residencial del entorno inmediato a la vivienda social	1989	1991	1890324	Universidad Central de Chile
5	Soluciones constructivas para paramentos de cierre vertical en madera de calidad térmica apropiada para su uso en viviendas de interés social *	1990	1992	1900213	Citec UBB
6	La ventilación en el diseño térmico de una vivienda *	1992	1995	1920264	Universidad de Concepción
7	Optimización e incorporación de sistemas pasivos a la arquitectura tradicional de la cuencia del salar de atacama	1992	1994	1921205	Universidad Católica del Norte, Universidad Federico Santa María
8	Desarrollo de un programa de mejoramiento de la calidad para la construcción	1994	1997	1940609	Pontificia Universidad Católica de Chile
9	Modelo de optimización térmica de viviendas	1996	1998	1961286	Universidad de Magallanes, Universidad de Concepción
10	Modelo para el diseño óptimo de ventanas en la construcción	1999	2001	1990405	Universidad de Concepción
11	Integración de consideraciones de eficiencia energética en el proyecto arquitectónico	2007	2009	11070148	Citec UBB
12	Enfriamiento ambiental de edificios de oficina a través de ventilación nocturna	2009	2011	1090602	Pontificia Universidad Católica de Chile
13	Base de información para el diseño de fachadas transparentes eficientes en Santiago	2010	2011	11100143	Pontificia Universidad Católica de Chile
14	Evaluation of different types of glazing and shading systems for improving energy performance and occupant's visual comfort of offices in central Chile	2011	2013	1111001	Pontificia Universidad Católica de Chile

Fuente **:** Elaboración propia con datos de repositorio institucional Conicyt / http://ri.conicyt.cl/
Nota **:** * Proyectos en los que ha participado el autor de tesis

6.2 Proyectos I + D Fondef

Ítem	Nombre Proyecto	Año Comienzo	Año Termino	Código	Institución Responsable
1	Mejoramiento de la gestión de producción en la construcción	2000	2002	D00I1004	Pontificia Universidad Católica de Chile
2	Determinación de los estándares de bienestar habitacional, para mejorar la calidad de la construcción de viviendas en Chile	2000	2003	D00I1039	Fundación Chile
3	Desarrollo experimental de especificaciones técnicas para el mejoramiento higrotérmico de muros de albañilería de ladrillo y hormigón. *	2001	2003	D01I1161	Citec UBB, Cementos Bío Bío S.A., P. Universidad Católica de Chile
4	Diseño por envolvente para la vivienda de madera: innovación tecnológica para fomentar el uso del pino radiata en Chile	2003	2005	D03I1020	Pontificia Universidad Católica de Chile, Dictuc S.A., Corma
5	Ahorro de energía y habitabilidad – transferencia de un paquete tecnológico para implementarlo en el sector habitacional	2004	2006	D04T2024	Fundación Chile
6	La Buena Casa: Diseño por envolvente para la vivienda de madera, Fase II: complejo techumbre y pisos	2006	2008	D06I1034	Pontificia Universidad Católica de Chile
7	Diseño y aplicación de un sistema de aseguramiento de calidad para obras de construcción habitacional en Chile, basado en criterios y estándares de desempeño *	2009	2011	D09I1162	Pontificia Universidad Católica de Chile, Citec UBB, Novatek, Urbaniza
8	Desarrollo e introducción del sistema de edificación pasiva en Chile *	2009	2012	D09I1081	Citec UBB, Hochschule Biberach, Holzbau Deutschland Institut
9	Desarrollo de bases técnicas y normativas para prototipos de vivienda modular, con énfasis en soluciones de emergencia, bajo criterios técnicos, geográficos y económicos	2009	2012	D09I1058	Universidad de Chile, Corma, Colegio de Ingenieros de Chile
10	Soluciones de muros de envolvente para casas de hormigón bajo criterios de desempeño energitérmicos, estructurales y constructivos	2010	2013	D10I1086	P. Universidad Católica de Chile, I. del Cemento y del Hormigón,
11	Establecimiento de clases de infiltración aceptable de edificios para Chile.*	2010	2014	D10I1025	Citec UBB, P. Universidad Católica de Chile

Fuente : Elaboración propia con datos de repositorio institucional Conicyt / http://ri.conicyt.cl/
Nota : * Proyectos en los que ha participado el autor de tesis

6.3 Proyectos I + D Corfo

Ítem	Nombre Proyecto	Año Comienzo	Año Termino	Código	Institución
1	Desarrollo de un sistema constructivo para edificar viviendas en ferrocemento.*	1994	1995	193-0273	Cementos Bio-Bio, Valmar Ltda., Citec UBB
2	Ensayo de paneles inyectados con poliuretano	1996	1997	195-0646	Industrias A.B. s.a.
3	Introducción y validación de un sistema constructivo en madera*	1997	1998	197-0985	CEPCO Ltda., Citec UBB
4	Diseño e implementación de paneles habitacionales modulares y evaluación de aislantes térmicos y acústicos	1998	1999	198-1272	Tiver ltda.
5	Viviendas industrializadas progresivas para el sector socio-económico bajo	1998	1999	197-1232	Edwards Navarro y Vial Ingeniería y Construcción S.A.
6	Desarrollo de un ensayo que permita validar el uso de bloques de hormigón en viviendas sociales	1999	2000	199-1732	Multicret S.A.
7	La madera en la vivienda social *	1999	2002	99CT3-V06	Instituto forestal
8	Vivienda social en ferrocemento en altura media *	1999	2001	99CT3-VO3	Cementos Bío-Bío, Valmar Ltda., Constructora Ribano, Citec UBB
9	Desarrollo de recomendaciones especiales para el diseño de viviendas sociales de albañilería de 1 y 2 pisos	2001	2003	CC-01	Instituto del hormigón y del cemento de Chile
10	Estudio y desarrollo de soluciones acústicas en base a celulosa.	2001	2002	201-2678	Sistemas Acústicos Modulares Ltda
11	Diseño y desarrollo de un nuevo tipo de aislamiento en poliuretano para la construcción	2001	2002	200-2488	Purteck Chile Ltda
12	Bases de certificación de calidad de la vivienda Dictuc.	2002	2004	202-3108	Dictuc s.a.
13	Desarrollo de un sistema constructivo industrializado de muros estructurales de acero hormigón*	2002	2003	01-A1-022	Constr. Río Los Ciervos Ltda., Cementos Bío Bío S.A., Citec UBB
14	Diseño y elaboración de instrumentos para la especificación y adquisición de materiales de construcción	2003	2005	02C8CM-03	Corporación de Desarrollo Tecnológico
15	Desarrollo de un sistema de apoyo a la planificación y gestión de producción en la construcción mediante un sistema computacional	2003	2005	02C8CT-02	Dictuc s.a.
16	Implementación de nuevos procesos productivos para sistemas de piso y cielo falsos y tabiquería interior incorporando nuevos componentes	2003	2004	203-3585	Dicsacom S.A.
17	Desarrollo de edificaciones en madera sólida clavada*	2003	2004	03-A1-184	JMS Ltda., Citec UBB

18	Desarrollo de una metodología para prevenir la ocurrencia de patologías en las viviendas sociales *	2004	2005	03C9CT-03	Instituto de la Construcción, P. Universidad Católica de Chile
19	Sistema nacional de información para la gestión de calidad en proyectos de construcción	2004	2006	03C9CT-05	Corporación de Desarrollo Tecnológico
20	DIT Chile: diseño de un sistema para desarrollar la capacidad de acreditar la idoneidad técnica de materiales de construcción y su adecuación de uso en obra	2004	2007	04C10ICT-02	Corporación de Desarrollo Tecnológico
21	Desarrollo de un sistema de edificación en madera en base a paneles modulares multi atributos listo para armar *	2005	2006	04-A1-292	Masisa S.A., Multicret
22	Elaboración de normas chilenas sobre uso eficiente de la energía en sector industrial y residencial	2005	2008	05CN11IXM-18	Instituto Nacional de Normalización INN
23	Actualización y estudio de normas chilenas para mejorar la calidad en el sector construcción	2006	2010	06CN12ICM-32	Instituto Nacional de Normalización INN
24	Creación de un centro tecnológico para la calidad de la vivienda en la Universidad del Bío-Bío *	2006	2006	05PFC01X-56	Citec UBB
25	Especifica.cl sistema de especificaciones técnicas de proyectos inmobiliarios y de construcción en Chile	2008	2009	08CS-0001	Universidad Diego Portales, Servicios GL Group Compañía Ltda.
26	Eficiencia energética y sustentabilidad aplicada a la construcción y espacios urbanos	2008	2009	08NF2-7141	Cámara Chilena de la Construcción A.G.
27	Revestimientos poli funcionales interiores contrachapados: una nueva opción de valor para los productos Infodema	2009	-	2009-6693	Infodema S.A.
28	Evaluación de estrategias de diseño constructivo y de estándares de calidad ambiental y uso eficiente de energía en edificaciones públicas, mediante monitorización de edificios	2009	2012	09CN14-5706	Instituto de la Construcción, Citec UBB, Decon UC, Dictuc S.A., IDIEM
29	Building energy programme: optimización energética en edificios residenciales	2009	2009	09PCS-3671	Dictuc S. A
30	Búsqueda de innovaciones constructivas en viviendas de madera con eficiencia energética utilizadas en España y Francia *	2009	2011	2009-6589	Catem S. A.
31	Evaluación del desarrollo de un material compuesto para el mejoramiento de la eficiencia energética en viviendas	2011	-	2011-10550	Empresa Eléctrica de la Frontera S. A., Universidad de Concepción
32	Innovaciones en la construcción de bloques de hormigón en Chile *	2011	-	11IDL1-10514	Instituto del Cemento y del Hormigón de Chile, Citec UBB
33	Diseño y Desarrollo de un Nuevo Sistema de Producción de Viviendas de Hormigón en Chile	2011	-	2011-9461	Deteco Ic S. A.
34	Desarrollo e Innovación de elementos constructivos de alto desempeño térmico-mecánico-acústico en base a caucho de desecho *	2011	-	2011-10772	Citec UBB, CIPA
35	Herramientas para el mejoramiento de la habitabilidad en las edificaciones	2011	-	2011-10010	Cámara Chilena de la Construcción, INN, Minvu
36	Diseño de soluciones tecnológicas constructivas para mejorar las condiciones de habitabilidad de La Araucanía mediante la industria.	2012	-	2012-13482	Cámara Chilena de la Construcción, Universidad Católica de Temuco,

37	Innovaciones en los sistemas de aislación térmica para el reacondicionamiento térmico de fachadas de construcciones habitacionales*	2012	2012	2012-16040	Citec UBB
38	Diseño e Implementación de Método de Certificación de Calidad Ambiental y Eficiencia Energética para Edificios de Uso Público *	2012	-	2012-13432	Cámara Chilena de la Construcción
39	Estudios de ingeniería para introducir en Chile un sistema constructivo de rápida ejecución para edificios de mediana altura	2012	-	2012-13553	CDT

Fuente **:** Elaboración propia con datos de repositorio interno Corfo. / http://repositoriodigital.corfo.cl/
Nota **:** * Proyectos en los que ha participado el autor de tesis

Anexo 7 **:** Matriz de análisis Foda y ejes estratégicos del plan de desarrollo

MATRIZ FODA	**Fortalezas (F)** 1. Voluntad política e institucionalidad. 2.- Grupo de investigadores capacitados. 3.- Alta calidad de la infraestructura existente. 4.- Liderazgo regional.	**Debilidades (D)** 1.- Marco regulador no apropiado. 2.- Investigación de desarrollo escasa. 3.- Falta cultura innovadora. 4.- Masa crítica insuficiente. 5.- Financiamiento reducido.
Oportunidades (O) 1.- Alta demanda nacional y regional (Latino América) de viviendas. 2.- Demanda social por calidad. 3.- Valorización social de la sustentabilidad. 4.- Demanda de eficiencia	**Estrategia (FO)** Eje 1: Innovación y competitividad Eje 2: Sostenibilidad	**Estrategia (DO)** Eje 4: Infraestructura Eje 3: Hábitat y bienestar Eje 5: Educación
Amenazas (A) 1.- Ingreso acrítico de tecnologías foráneas. 2.- Uso acrítico de norma técnicas. 3.- Barreras de impuestos y comerciales.	**Estrategia (FA)** Eje 1: Innovación y competitividad	**Estrategia (DA)** Eje 6: Regulaciones y gobernanza

Fuente: Elaboración propia

Anexo 8 : Matriz de objetivos estratégicos y acciones priorizadas del plan de desarrollo

Eje Estratégico 1: Innovación y Competitividad.

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 01.1: Fomentar la innovación y el emprendimiento en procesos, sistemas de construcción de viviendas e instalaciones que favorezcan la eficiencia energética, sustentabilidad y productividad económica de las obras de construcción habitacional.	**Objetivo Específico 01.1.1:** Incrementar el volumen y la calidad de los sistemas constructivos disponibles en el mercado.	Número de nuevos sistemas constructivos inscritos en la DITEC MINVU.	LA 01.1.1:1.: Desarrollar innovación tecnológica en sistemas de construcción y procesos con atributos diferenciadores de sustentabilidad.	16 A
			LA 01.1.1.2: Desarrollar sistemas de etiquetados y certificación energética y ambiental de materiales, elementos sistemas constructivos e instalaciones.	13 B
	Objetivo Específico 01.1.2: mejorar la eficiencia energética y uso de nuevas tecnologías.	Número de nuevas instalaciones de servicio y sistemas en el mercado	LA O1.1.2.1: Desarrollar instalaciones pasivas o híbridas eficientes y de bajo costo para mejorar el desempeño energético y ambiental de las viviendas.	10 B
			LA 01.1.2.2: Desarrollar innovaciones tecnológica para incorporar sistemas Net-Metering y/o criterios cero energía al mercado de viviendas en Chile.	7 C
			LA 01.1.2.3: Desarrollar innovaciones en sistemas de gestión energética de viviendas y edificios colectivos.	12 B
Objetivo Estratégico 01.2: Fomentar la innovación y el emprendimiento en materiales y elementos de construcción de uso en vivienda que favorezcan la eficiencia energética, sustentabilidad y productividad económica de las obras de construcción habitacional.	**Objetivo Específico 01.2.1:** Incrementar el volumen y la calidad de los materiales disponibles en el mercado.	Número de nuevos materiales y elementos certificados en el mercado.	LA 01.2.1.1: Impulsar una base de datos públicas de materiales, elementos, instalaciones y sistemas de construcción certificados.	17 A
			LA O1.2.1.2: Desarrollar innovaciones en materiales y elementos con mejores desempeños energéticos y ambientales (nuevos, mejorados o adaptados).	17 B
			LA 01.2.1.3: Impulsar el desarrollo de la nanotecnología aplicada al mejoramiento energético y ambiental de materiales.	8 C
			LA 01.2.1.4: Impulsar el desarrollo de materiales con cambio de fase para el mejoramiento de la calidad energética de la edificación habitacional.	8 B
Objetivo Estratégico 01.3: Fomentar la innovación y el emprendimiento en diseño pasivo de viviendas mejor adaptadas a las condiciones climáticas del territorio nacional y cultura de uso de viviendas en Chile.	**Objetivo Específico 01.3.1:** Mejorar el diseño pasivo y arreglos urbanos de viviendas en Chile.	Número de nuevos diseños arquitectónico de viviendas.	LA 01.3.1.1: Innovar en el diseño arquitectónico y estrategias de diseño pasivo utilizadas en los proyectos de viviendas.	13 A
			LA 01.3.1.2: Innovar en el diseño urbano y las estrategias de aprovechamiento pasivo en proyectos inmobiliarios (de barrios sustentables).	12 B
	Objetivo Específico 01.3.2: Mejorar el proceso de diseño de viviendas y barrios en Chile.	Número de nuevas viviendas y barrios con proceso de diseño integrado.	LA O1.3.2.1: Innovar en los procesos de diseño de vivienda en Chile. Incorporar criterios de “performance based building design” u otros.	16 A
			LA 01.3.2.2: Desarrollar ciencia y tecnología en sistemas de protección solar y de aprovechamiento pasivo de energía en Chile.	12 B
Objetivo Estratégico 01.4: Promover la industria y el mercado de la construcción sustentable.	**Objetivo Específico 01.4.1:** Crear empresas de base tecnológica	Número de nuevas empresas creadas (Start-ups y spin-offs). Número de nuevos productos en el mercado. Número de viviendas en el mercado.	LA 01.4.1.1: Impulsar la creación de subsidios del estado para la adquisición de viviendas nuevas que incorporen criterios de sustentabilidad certificados.	16 A
			LA 01.4.1.2: Desarrollar planes de promoción, mercadeo y marketing de construcción sustentable.	14 B
	Objetivo Específico 01.4.2: Incrementar el apoyo del Estado para el mejoramiento de la E.E.	Número de subsidios entregados.	LA 01.4.2.1: Aumentar el número y montos de subsidios para el reacondicionamiento térmico de viviendas.	15 B
			LA 01.4.2.2: Desarrollar emprendimientos tecnológicos e incubar empresas vinculadas al mercado de la construcción sustentable.	10 C

Eje Estratégico 2: Sostenibilidad.

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 02.1: Fomentar la incorporación de criterios de sustentabilidad en la edificación habitacional.	**Objetivo Específico 02.1.1:** Desarrollar información de base experimental para apoyar el desarrollo de normas y estándares.	Número de nuevos estándares definidos	LA 02.1.1.1: Desarrollar ciencia e investigación aplicada para desarrollar información y criterios para definir estándares	18 A
			LA 02.1.1.2: Desarrollar evaluaciones económicas y sociales para soportar el establecimiento de estándares de exigencias energéticas y ambientales.	18 A
	Objetivo Específico 02.1.2: Desarrollar nuevas ordenanzas y/o mejorar las actuales.	Número de nuevos estándares en la OGUC.	LA 02.1.2.1: Desarrollar estándares de construcción sustentable y sus sistemas de acreditación.	16 A
			LA O2.1.2.2: Desarrollar itemizados técnicos regionales de tipo prestacional adaptados a las condicione climáticas y culturales de cada Región (15).	16 A
Objetivo Estratégico 02.2: Incentivar la adopción del concepto de ciclo de vida para la evaluación de la edificación habitacional.	**Objetivo Específico 02.2.1:** Incrementar en el mercado el número de viviendas y materiales con análisis de ciclo de vida.	Número de materiales producidos localmente con análisis de ciclo de vida.	LA 02.2.1.1: Desarrollar base de datos locales y herramientas debidamente adaptadas para el análisis de ciclo de vida de construcciones de Chile.	11 C
			LA O2.2.1.2: Desarrollar y promover el uso de sistemas prestacionales de control, aseguramiento de calidad y certificación sustentable.	13 B
		Número de viviendas que incorporan análisis de ciclo de vida.	LA 02.2.1.3: Desarrollar y promover el análisis de ciclo de vida en proyectos inmobiliario e impactos asociados como elementos de juicio.	9 C
Objetivo Estratégico 02.3: Promover el diseño pasivo de construcciones habitacionales y el uso de ERNC para atender sus necesidades de servicios de calefacción y/o refrigeración, ventilación e iluminación.	**Objetivo Específico 02.3.1:** Consolidar la modalidad concurso para viviendas en Chile con criterios de eficiencia energética.	Número de concursos de construcción sustentable	LA 02.3.1.1: Promover la realización de concursos de construcción sustentable de viviendas sociales	10 A
	Objetivo Específico 02.3.2: Incrementar el número de viviendas en el mercado que incorporen diseños e instalaciones con criterios de E.E.	Número de viviendas que incorporan ERNC.	LA 02.3.2.1: Innovar en los diseños de viviendas y elementos de aprovechamiento pasivo en las distintas zonas climáticas de Chile.	10 A
			LA 02.3.2.2: Innovar en las fuentes de energía utilizadas en viviendas (incorporación de ERNC).	10 C
			LA 02.3.2.3: Desarrollar herramientas para evaluar desempeños energéticos y ambientales y apoyar procesos de diseño de viviendas e instalaciones.	15 A

Eje Estratégico 3: Hábitat y Bienestar.

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 03.1: Contribuir al mejoramiento de la cualidad habitable de la edificación residencial.	**Objetivo Específico 03.1.1:** Mejorar la cualidad habitable de la vivienda.	Número de estándares de clima interior	LA 03.1.1.1: Desarrollar la ciencia básica del confort adaptativo aplicable a construcciones habitacionales en Chile.	10 B
			LA 03.1.1.2: Desarrollar y validar estándares aceptables de clima interior para viviendas en Chile.	11 C
	Objetivo Específico 03.1.2: Mejorar la regulación y control del clima interior e instalaciones.	Número de instalaciones desarrolladas para control clima interior.	LA 03.1.3.: Desarrollar sistemas domóticos de regulación y control clima interior de bajo costo.	11 C
Objetivo Estratégico 03.2: Reducir las patologías de construcción asociadas al mal comportamiento higrotérmico del parque de construcciones.	**Objetivo Específico 03.2.1:** Desarrollar nuevas herramientas para el control y análisis de patologías.	Número de reclamos por patologías	LA 03.2.1.1: Desarrollar y validar métodos prestacionales para realizar diagnosis de fallas	17 A
			LA 03.2.1.2: Desarrollar y promover métodos prestacionales de control, aseguramiento de calidad y certificación de comportamiento higrotérmico	18 A
	Objetivo Específico 03.2.2: Incorporar criterios de diseño higrotérmicos a las ordenanzas	Nuevas ordenanzas con criterio de diseño higrotérmico	LA 03.2.2.1.: Realizar estudios experimentales de fenómenos de transporte y desarrollar herramientas de simulación para hacer análisis predictivo.	16 A
			LA 03.2.2.2.: Desarrollar criterios de diseño higrotérmico y soluciones de diseño adaptadas a los climas del territorio y culturas de uso de viviendas.	16 A
			LA 03.2.2.3: Desarrollar un zonificación higrotérmica y recomendaciones de diseño higrotérmico para prevenir patologías.	15 B
Objetivo Estratégico 03.3: reducir los niveles de emisiones y contaminantes que impactan en el confort ambiental.	**Objetivo Específico 03.3.1:** Incrementar el uso de sistemas que ayuden a la descontaminación.	Número de viviendas con sistemas descontaminantes.	LA 03.3.4: Desarrollar e impulsar el uso de sistemas que permitan la separación de residuos sólidos y materia orgánica en viviendas y edificios.	12 C
			LA 03.3.1: Implementar sistema de etiquetado de emisiones de instalaciones de calefacción y producción de agua caliente sanitaria.	10 C
	Objetivo Específico 03.3.2: Disponer de mejor información ambiental para decidir uso de materiales e instalaciones	Número de viviendas con materiales y artefactos con baja o nula emisiones	LA 03.3.2.1: Desarrollar soluciones para reducir la contaminación acústica, lumínica, atmosférica y otras que afectan el clima interior.	10 C
			LA 03.3.2.2: Reducir el uso de materiales y artefactos contaminantes.	10 C

Eje Estratégico 4: Infraestructura

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 04.1: Apoyar la inversión en investigación y desarrollo aplicado a la construcción sustentable.	**Objetivo Específico 04.1.1:** Incrementar el volumen y la calidad de la I+D.	Número de proyectos adjudicados.	LA 04.1.1.1: Desarrollar tres concursos de I+D temáticos en construcción sustentable de edificaciones residenciales.	15 A
			LA 04.1.1.2.: Impulsar la vinculación universidad-empresa para la construcción sustentable.	16 B
	Objetivo Específico 04.1.2: Incrementar el números de centros creados y/ o dedicados a la I+D.	Número de nuevos Centros dedicados a tareas de I+D.	LA 04.1.2.1: Impulsar un programa gubernamental de innovación y emprendimiento en construcción sustentable.	16 A
			LA 04.1.2.2: Impulsar el desarrollo de nuevos centros de excelencia en I+D en construcción sustentable y/o fortalecer los existentes.	13 A
			LA 04.1.2.3: Impulsar la creación en la VIII Región del Cluster de Construcción Sustentable de Chile.	10 B
Objetivo Estratégico 04.2: Apoyar la inversión en creación de laboratorios para apoyar procesos de investigación, fiscalización y control.	**Objetivo Específico 04.2.1:** Mejorar la capacidad país en laboratorios de referencia.	Número de nuevos laboratorios creados.	LA 04.2.1.1: Impulsar un programa gubernamental para la instalación de un laboratorio de acreditación de calidad en las regiones donde no se cuenta y reforzar los existentes.	15 A
			LA 04.2.1.2: Instalar técnicas y protocolos estandarizados de acreditación de calidad común en todos los laboratorios de Chile.	14 B
			LA 04.2.1.3: Desarrollar e impulsar nuevos métodos y herramientas para apoyar procesos de fiscalización de calidad.	15 A
	Objetivo Específico 04.2.2: Crear un moderno sistema de acreditación nacional que cubra todo el territorio.	Sistema nacional de acreditación con presencia en las 15 regiones.	LA 04.2.2.1: Reforzar el sistema de acreditación nacional de calidad para cubrir todo el territorio nacional.	13 B
			LA 04.2.2.2: Desarrollar sistemas de gestión de servicios de acreditación de calidad para entregar servicios oportunos y a precios razonables.	14 B
Objetivo Estratégico 04.3: Apoyar la inversión en la formación de capital humano avanzado.	**Objetivo Específico 04.3.1:** Incrementar la masa crítica país.	Número de nuevos Magister y Doctores en el área.	LA 04.3.1.1: Impulsar un programa gubernamental para financiar la formación de capital humano avanzado en Chile y el Extranjero.	13 A
			LA 04.3.1.2: Promover e impulsar la creación en Chile de nuevos programas de magister y doctorales que aborden temas de construcción sustentable.	13 B

Eje Estratégico 5: Educación.

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 05.1: Mejorar las competencias técnicas y profesionales en construcción sustentable.	**Objetivo Específico 05.1.1:** Mejorar las capacidades técnicas y profesionales del personal y del país en el área.	Número de nuevos técnicos, profesionales y otro personal entrenado.	LA 05.1.1.1: Desarrollar y ejecutar programas de formación en construcción sustentable para carreras técnicas y universitarias.	14 A
			LA 05.1.1.2: Desarrollar y ejecutar talleres y seminarios en temáticas de construcción sustentable para distintos públicos.	15 A
			LA 05.1.1.3: Capacitar a las unidades de fiscalización del estado y de la industria en técnicas de control de calidad de construcciones habitacionales.	13 A
	Objetivo Específico 05.1.2: Mejorar los programas de formación y los métodos de enseñanza, aprendizaje y transferencia tecnológica del país en el área.	Número de nuevos programas de formación operando.	LA 05.1.2.1: Desarrollar nuevos métodos de enseñanza aprendizaje y modelos de transferencia tecnológica para favorecer la adopción de tecnologías de construcción sustentable.	12 B
		Número de carreras que incluyen temáticas de construcción sustentable.	LA 05.1.2.2: Incentivar la creación de certificaciones profesionales y técnicas en las distintas áreas de construcción sustentable.	14 B
Objetivo Estratégico 05.2: Educar y sensibilizar en construcción sustentable a toda el colectivo de la construcción para la valorización y creación de una cultura de construcción sustentable	**Objetivo Específico 05.2.1:** Sensibilizar a la sociedad con el Plan.	Número de seminarios de sensibilización.	LA 05.2.1.1: Realizar programas de sensibilización dirigidos a la población, industria y autoridades políticas	12 A
			LA 05.2.1.2: Impulsar el establecimiento de redes de cooperación nacional e internacional para favorecer la trasferencia y adopción de mejores prácticas.	10 B
			LA 05.2.1.3: Impulsar plataforma de información pública para trasparentar y darle valides a la información relativa a construcción sustentable.	12 B
	Objetivo Específico 05.2.2: Disponer de manuales técnicas y documentos de distinta naturaleza para apoyar procesos de diseño, construcción y difusión.	Número de manuales y documentos de enseñanza y difusión.	LA 05.2.2.1: Desarrollar manuales de la especialidad y documentos de distinta naturaleza para favorecer la enseñanza, el aprendizaje y la difusión de la construcción sustentable.	15 A

Eje Estratégico 6: Regulaciones y Gobernanza

OBJ. ESTRATÉGICO	OBJ. ESPECÍFICO	INDICADORES	LÍNEAS DE ACCIÓN	PRIORIDAD
Objetivo Estratégico 06.1: Actualizar y perfeccionar la Reglamentación Térmica de Viviendas R. T.	**Objetivo Específico 06.1.1:** Disponer de una Reglamentación Térmica que promueva la calidad y la innovación.	Incorporación de estándares mejorados a la R.T. Número de nuevos estándares incorporados a la R.T.	LA 06.1.1.1.: Desarrollar investigación de base experimental para soportar técnica, económica y socialmente la incorporación de estándares a la R.T.	18 A
			LA 06.1.1.2.: Definir e incorporar a la R.T. nuevos estándares y mejorar los actuales.	18 A
			LA 06.1.1.3: Desarrollar una nueva R.T. más de acuerdo con el estado del arte de este tipo de instrumentos en el mundo.	15 B
			LA 06.1.1.4: Establecer zonificaciones para propósitos de diseño arquitectónico que asocien de mejor forma zonas con clase de exigencias.	16 A
	Objetivo Específico 06.1.2: Evaluar y actualizar periódicamente la R.T.	Informes anuales de evaluación.	LA 06.1.2.1: Desarrollar e impulsar un sistema público privado de monitoreo, revisión y actualización periódica de la R.T.	12 B
			LA 06.1.2.2.: Perfeccionar las herramientas del MINVU CCLT_CL_V2 y CEV_V_1.0 utilizadas para calificar energéticamente viviendas.	12 B
Objetivo Estratégico 06.2: Mejorar el soporte de normas técnicas de la Reglamentación Térmica de Viviendas.	**Objetivo Específico 06.2.1:** Desarrollar información de bases experimental para apoyar el establecimiento de normas y estándares.	Número de nuevas normas incorporadas a las ordenanzas.	LA 06.2.1.1.: Desarrollar investigación de base experimental para adaptar normas internacionales de requisitos cuando ello sea posible.	12 C
			LA 06.2.1.2: Crear nuevas normas nacionales debidamente soportadas en conocimiento desarrollado localmente o adoptar directamente normas internacionales, en especial normas de ensayos.	15 B
	Objetivo Específico 06.2.2: Consolidar la institucionalidad de la creación de normas y reglamentos.	Número de nuevas normas incorporadas a las ordenanzas.	LA 06.2.2.1.: Desarrollar e implementar un moderno sistema público de acreditación de exigencias de calidad de viviendas.	13 B
			LA 06.2.2.2: Perfeccionar el sistema de estudio, creación e incorporación de normas a las ordenanzas de construcción.	11 B
			LA 06.2.2.3: Propiciar el financiamiento del estado para el estudio y creación de normas de interés público.	11 B
Objetivo Estratégico 06.3: Implementar el Plan de Desarrollo y sistema de seguimiento y evaluación.	**Objetivo Específico 06.3.1:** Crear y consolidar la institucionalidad del Plan de Desarrollo.	Instancia coordinadora definida y a cargo. Número de instituciones participando en el Plan. Sistema de monitoreo y gestión instalado.	LA 06.3.1.1: Establecer y consolidar la institucionalidad gestora y coordinadora del Plan de Desarrollo.	14 A
			LA 06.3.1.2: Establecer un sistema de gestión y evaluación del Plan de Desarrollo que permita evaluaciones a mediano y largo plazo.	14 B
	Objetivo Específico 06.3.2: Promover la coordinación, cooperación, financiamiento y ejecución del Plan	Número de instituciones participando en el Plan.	LA 06.3.2.1: Impulsar instancias de coordinación y cooperación entre los actores involucrados en el Plan de Desarrollo.	13 B
			LA O4.3.2.2: Impulsar instancias de cooperación publico privada para gestar financiamiento, desarrollo y promoción del Plan.	15 A

Anexo 9 **:**Abreviaciones y siglas

°C	Degrees Celsius
°CW	Degrees clockwise
2D	Two dimensional
3D	Three dimensional
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
ASTM	American Society for Testing and Materials
BID	Inter American Development Bank
BSC	Balanced Scorecard
CChC	Chilean Construction Chamber
CITEC	Investigation of construction technologies center
CIVA	Research of the austral dwellings center
CMI	Integral control systems
CNE	National Energy Commission
CO2	Carbon dioxide
DAFO	Weaknesses- Threats – Strengths - Opportunities
dB(A)	A-weighted decibel
DFL	Decree forces of law
DICTUC UC	Technology and Science research Department Catholic University
DITEC MINVU	Technical direction of Ministry of Housing and Land Development
dm3s-1	Cubic decimetre per second
EC	European Commission
ECBCS	Energy Conservation in Buildings and Community Systems
EDSL	Environmental Design Solutions Limited
EEC	Zero energy buildings
EEN	Clear energy buildings
EIFS	External Insulatión & Finish System
EN	European standard
EPBD	European Directive on Energy Performance of Buildings
EPS	Expanded polystyrene
ERNC	Non conventional renewable energy
EU	European Union
FONDEF	Fund for the Promotion of Scientific and Technological
FONTEC	National Fund of Technological and Productive Development
GW	Gigawatt (109 watts)
GWh	Gigawatt hours
h/1	Air changes per hour
HVAC	Heating, ventilating and air conditioning
IC	Chilean Construction Institute
IDIEM	Research center for innovation and development of materials and structures
IEA	International Energy Agency
INE	National Statistics Institute
ISO	International Organisation for Standardisation
kW	Kilowatt (103 watts)

kWh/m²/yr	Kilowatt hours per square metre per year
LBL	Lawrence Berkeley Laboratory
LHS	Latin Hypercube Sampling
LPG	Liquefied petroleum gas
m	Metre
m/s	Metres per second
m²	Square metres
m3	Cubic metres
MINVU	Ministry of Housing and Land Development
mm	Millimetre
MPHT	Higrothermal test module
MPST	Therm Solar test module
MW	Megawatt (106 watts)
NCh	Chilean standard
OGUC	General ordinance of urbanism and construction
Pa	Pascal
PIB	Internal brute product
PLC	Logical programmable controller
PLEA	Passive and Low Energy Architecture
RT	Thermal Regulation
RIBA	Royal Institute of British Architects
SIP	System Insulation Panel
ST	Solar transmittance
TAS	Thermal Analysis Simulation Software
U	Thermal transmittance
UA	Energy lost by transmission
UBB	Bío-Bío University
UC	Catholic University
UCL	Université Catholique de Louvain
UF	Chilean account unit
W/m²	Watt per square metre
W/m²K	Watt per square metre per Kelvin
WMO	World Meteorological Organisation