Air infiltration in Chilean housing:
A baseline determination

RODRIGO FIGUEROA SAN MARTÍN, ARIEL BOBADILLA M., DANIELA BESSER J., MURIEL DÍAS C., ROBERTO ARRIAGADA B., RODRIGO ESPINOZA M.

CITEC UBB, Universidad del Bío Bío, Concepción, Chile

ABSTRACT: Air infiltrations can strongly determine the energy efficiency of a building and be a major cause of heat loss. This paper presents a study focused on establishing the air infiltration baseline in Chilean housing, by means of the analysis of on-site test results made according to the UNE EN 13829 Standard. The study was performed to a representative sample of dwellings built in the years 2007 and 2010. The sample was designed with a 95% of confidence limit and a 10% of error rate, considering the prevailing material of walls and grouping type as the variables of interest. For the purposes of this study a total of 191 housing units were analyzed. Statistical techniques were used for establishing inferences and levels of significance of the factors under study, which explain that the prevailing material of walls variable is the most appropriate for the elaboration of the baseline.
Therefore, the air infiltration baseline for predominant material of walls is established with the following n50 values: concrete=9.0 ach; brickwork=11.8 ach; brickwork plus lightweight construction=15.0 ach; timber=24.6 ach; other materials=10.2 ach.
The results allow the determination of the starting point for future improvements in the energetic quality of Chilean housing.
Keywords: Air infiltration baseline; airtightness; energy environmental quality

INTRODUCTION

Through the agreement between the National Commission for Scientific and Technological Research (CONICYT) and the Universities of Bío-Bío and Católica de Chile, it was agreed to develop the FONDEF Project D10I1025, “Establishment of acceptable air infiltration levels for buildings in Chile” (“Establecimiento de clases de infiltración aceptables de edificios para Chile”), with an implementation deadline of 30 months starting from December 2011.

Responsible for the project execution and transfer was the Technological Association formed by: the Technical Division of Housing Study and Promotion (DITEC) of the Ministry of Housing and Urban Planning; the Architecture Department of the Ministry of Public Works; the Chilean Energy Efficiency Agency of the Ministry of Energy; the Research Centre on Construction Technologies of the Universidad del Bío-Bío (CITEC UBB); the Faculty of Civil Construction of the Pontificia Universidad Católica de Chile with its Department in Construction Office (DECON UC); the Technological Resource Centre of France (NOBATEK); and the building companies Pocuro S.A., Venteko S.A., Indalum S.A, Alcorp S.A and Wintec S.A.

The problem motivating the proposal derives from the need of improving the airtightness of Chilean housing. Nowadays, this represents a problem that affects the environmental and energetic performance of buildings, their inhabitable quality, the quality of life of the population and, in a considerable proportion, the national energy costs, with economic and social consequences of great significance for the Chilean industry and the state. 25% of the primary energy used in the country is allocated to the building sector, being an important fraction of this number (30% approximately) [1], utilized for thermal conditioning. This phenomenon is mainly explained by the poor thermal quality of the buildings and the poor performance of their facilities. The poor thermal performance of housing causes in Chile costs near to USD 1000 millions per year [2], along with other difficult to quantify but not less significant losses, which come from the harm to health and people’s productivity as a consequence of occupying uncomfortable spaces, resulting from poor energetic and environmental performance of buildings. The thermal loads produced by undesired air infiltrations through the building envelope determine an important part of the energy demand for its thermal conditioning. The air infiltrations, that always mean thermal flux, either heat gains or heat losses, depend mostly on the air permeability properties of the materials that constitute the envelope: a practically unknown, unregulated and uncontrolled feature of the Chilean housing stock.

Previous experimental assessments demonstrate that infiltration levels in national buildings exceed between 2 and 10 times the maximum acceptable levels allowed in

European countries. This situation explains the moderate progress achieved nowadays in terms of reducing the energy destined to thermal conditioning of buildings. Additionally, it jeopardizes the efficiency and profitability of the strategies used in Chile for improving the energy efficiency of them.

The Chilean Thermal Regulation states requirements only for heat losses due to transmission, summarized in the indicator U (W/m2°C). It establishes for each of the seven thermal zones in which the country is divided, a maximum acceptable heat loss due to transmission through the non-transparent envelope components [3]. Currently, it does not exist any guideline in Chile focused on regulation and control of heat losses due to air infiltrations. Therefore, an important component of the energy demand of buildings, which according to certain exploratory studies [1] can in some cases even represent a 60% of it, is nowadays uncontrolled in Chile. The main fact is that the envelope airtightness is a variable not taken into account when focusing on energy savings in the Chilean buildings.

The hypothesis for the development of the project states that "It is possible to define and establish standards of air permeability, together with acceptable infiltration levels for buildings, regarding the different climatic zones of Chile. At the same time, to establish the regulation and control methods for those standards, through all the execution stages of the project, as well as the necessary actions for its appropriate implementation during the design, construction and operation of buildings in the country, in order to reduce to acceptable limits the impact that air infiltrations have on the energy demand of Chilean buildings."

The FONDEF Project D10 I 1025 considers its development in four stages: the first stage aims to establish the baseline of air infiltrations in the building sector of Chile; the second stage, to set airtightness standards for buildings according to its location (i.e. weather); the third stage, to elaborate technical support for helping the building sector; and the fourth stage, to transfer and spread the obtained results, which will be accomplished under a scheme of free availability and usage.

METHODOLOGY

The first stage of the previously explained project scheme is called "determination of the infiltration baseline of buildings in Chile" and brings crucial information regarding the predominant building typologies, which conform the Chilean housing stock, together with making quality judgements on their airtightness properties. Additionally, it aims to evaluate potentialities of improvement and optimization for each of them; and finally, to set parameters and criteria to define infiltration levels or degrees of tightness, which will guide future constructions in Chile.
The technique for determining the infiltration baseline of buildings in Chile consists on the following main constitutive parts:

a. Sample selection and sizing
b. Sample measurement
c. Data analysis

Sample selection and sizing:
Statistical techniques were used to define a representative sample of dwellings in Chile, considering 90% of the Chilean housing stock. The information source is the yearly construction report (Anuario de la Edificación) of the National Statistics Institute (INE), i.e., the annual edification authorized in different town halls of the country that record the statistics of INE [4, 5]. The sample of the study is formed by dwellings built in 2007 and in 2010, distinguished by the following features of interest:

Predominant Material of Walls: concrete; brickwork; brickwork plus lightweight structure; timber; other materials.

Grouping Type: detached, semi-detached and row houses.

Through the design of the statistical sampling, a representative sample of the population under study, consisting of 135 units, with a confidence limit of 95% and a sampling error of 10%, was established.

Sample Measurement:
Experimental techniques were used for measuring the air permeability, and with it, the tightness of every sample unit. This specific property of the envelope corresponds to the response variable in the experiment, expressed in air changes per hour (ach) of a building subjected to a pressure difference of 50Pa (n50 value). The pressurization technique Blower-Door was used as described in the UNE-EN 13829 Standard "Thermal Performance of building-Determination of air permeability of building – Fan Pressurization method" [5].

In order to know the permeability properties of the housing units, the Method A described in the regulation was used [6]. Additionally, smoke tests were performed in order to localize singular air leakage points through the envelope of some dwellings, being that crucial information for potential improvements. The following is a summary table of the study results, using Method A:

Table 1: Summary of Study Results, Method A

Predominant Material in Walls	Suggested Sample	Studied Sample	Minimum n50 value (ach)	Maximum n50 value (ach)	Average n50 value (ach)
Concrete	54	60	2.6	28.6	9.0
Brickwork	35	52	4.3	19.6	11.8
Brickwork plus Lightweight Structure	13	42	2.3	49.2	15.0
Timber	17	19	4.5	49.8	24.6
Other materials	16	16	3.3	15.7	10.2

Figure 1: CITEC UBB staff performing a Blower Door Test

A total of 191 tests were performed, achieving the minimum suggested sample of 135 units. A first analysis of the obtained test results showed a considerable difference between the airtightness properties when comparing the different material categories, obtaining an average n50 value of the sample of 12.9 ach, with minimum values of 2.6 ach and maximum of 49.8 ach.

Figure 2: Smoke test performed to a timber house

Furthermore, the smoke tests performed allowed the observation of the main leakage points. Figure 2 shows the leakages in the wall and concrete slab joint of a detached timber house.

Data Analysis

Statistical techniques were used in order to establish inferences and significance levels of factors associated with airtightness under study, such as materials, grouping type, building age, etc. The main techniques were:

Box-plot diagram: this technique permitted the identification of variable data distribution and dispersion, and the representation of median, quartiles (1 and 3), outliers and extreme values [6].

A first analysis revealed different forms of data distribution, i.e., of airtightness properties in the five grouping types. These differences were also important in the airtightness values of the five building types: concrete buildings were in the highest airtightness levels, whereas the timber buildings were in the lowest airtightness levels. The dispersion rates were also very dissimilar.

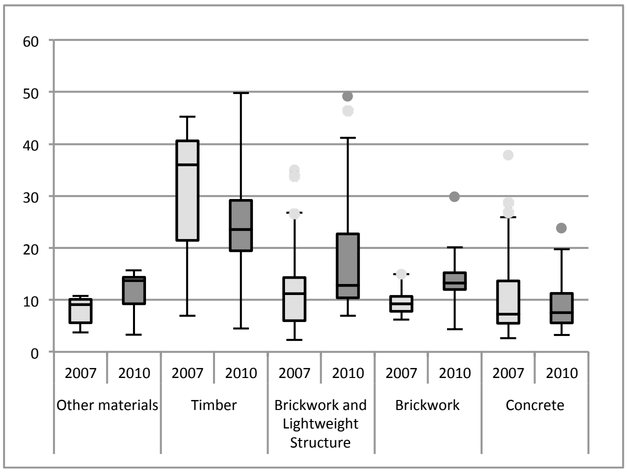

Figure 2: Box-plot diagram by year and material

The differences at this analysis level were compatible with the kind of material used, its homogeneity and building system characteristics, as well as the envelope performance quality.

Charts sorted by grouping type and construction year were used to understand the connections in the collected data for each material.

In the case of concrete housing, more centred medians and relatively low dispersion were observed, which were expected in this particular case because of the building type and the homogeneity of the material—with an average n50 value of 9.0 ach. Generally, data dispersion is related to the airtightness level of other building areas or elements, such as windows, doors and roofs. These elements can be very different and more influenced by the performance quality than by the concrete building itself, which tends to be compact, naturally airtight and less influenced by the performance quality.

In the case of brickwork housing, asymmetrical medians and a great dispersion of the data were observed—with an average n50 value of 11.8 ach. It is estimated that the data dispersion is related to other elements of the building envelope, such as doors, windows, roofs, etc. These elements can be very varied and more influenced by the performance quality than by the brickwork building itself, since the construction process of brickwork is perceived as well-accomplished and the concrete mortar and brick materials are considered to be naturally airtight.

In the case of brickwork plus lightweight structure housing, asymmetrical medians and great data dispersion were observed—with an average n50 value of 15.0 ach. The incorporation of lightweight structure walls made of timber and steel profiles implies a bigger quantity of joints. Therefore, it is concluded that the quality of the execution, together with the material quality, are very important factors in the dwelling performance. Additionally, it was inferred that the data dispersion was related to the airtightness level of other construction elements or parts, such as windows and doors.

In the case of timber housing, asymmetrical medians and great data dispersion were observed. According to the predominant material used in walls, the highest infiltration values of the five building types were observed in this category. The average n50 value for timber housing is 24.6 ach with a standard deviation of 12.6. Timber buildings are characterized by a greater quantity of joints that are susceptible to faults. In this case, the performance quality has a much greater role and, together with the material quality, are the main determiners of the building envelope airtightness.

Mann-Whitney test: This technique is based on the median comparison for finding statistically significant differences between studied groups [6]. Two tests were performed to analyze the significance between variables, the first one related to construction years, and the second one related to the connection between the grouping type by material variable and the construction year variable.

For the two tests, the p-value of all analyzed variations was bigger than 0.05. In consequence, the null hypothesis could not be rejected, i.e., for the first case, there was no statistically significant difference associated to the construction years 2007 and 2010; and for the second case, there was no statistically significant difference associated to the materials according to grouping typology for both analyzed years 2007 and 2010.

Multiple correspondence analysis: descriptive technique that summarizes the air permeability response variable characterized as "under the median" or "above the median". Through the analysis, two groups were identified. The first one composed of residential buildings of row houses and concrete as predominant material for walls, associated to values below the sample average 12.9 ach. The second group consisted of detached and semi-detached houses of brickwork plus lightweight structure, brickwork, and others materials as predominant material for walls, all related to values above the sample average 12.9 ach.

RESULTS

From the performed data analysis it was concluded that there is significant statistical evidence to generate an infiltration baseline for Chile. The analysis of the different factors associated with the building airtightness (materials, grouping type, building age) showed that the predominant material of walls variable is the most suited for its creation, because of the greater differences observed. Therefore, the factors to be considered within this study in order to create the airtightness baseline for Chilean housing are:

Predominant material of walls with its five levels: concrete, brickwork, brickwork plus lightweight structure, timber, and other materials.

The housing baseline is the average value according to the predominant material of walls at its five levels, with a range of expected values at a 95% of confidence.

The following table summarizes the air infiltration baseline values of the Chilean housing:

Predominant material of walls	Baseline n50 value (ach)	Expected Values	
		Maximum n50 (ach)	Minimum n50 (ach)
Concrete	9.0	7.8	11.2
Brickwork	11.8	10.9	13.4
Brickwork and Lightweight Structure	15.0	11.7	13.8
Timber	24.6	18.6	30.6
Other Materials	10.2	7.9	12.6

Table 2: Air infiltration baseline values of Chilean housing

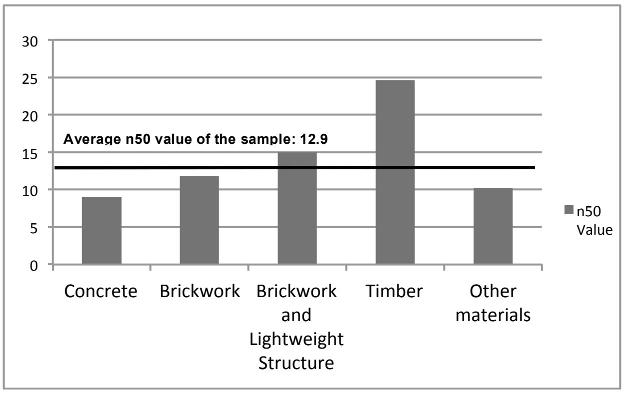

Figure 3: Graphic baseline values of Chilean housing

The reasons explaining these results can be very different and inherent to each type. They are influenced by the labour execution quality, material quality, used technologies, among others. The concrete housing type has the highest airtightness level of the five types. This result is explained by the concrete natural compactness and airtightness, and the lower influence of labour execution quality. It is presumed that the air leakage areas are in other elements of the building envelope such as doors, windows and installation ducts.

On the contrary, the timber type has the lowest airtightness level of the five types. Timber buildings have a great quantity of joints, where labour execution quality, together with material quality and used technologies, essentially determine the observed values.

CONCLUSIONS

The first study that reports the airtightness levels of the Chilean housing was performed. The evaluation of designed sample made possible to collect the necessary data in order to determine the air infiltration baseline of Chilean dwellings, which is representative for the 90% of the Chilean housing stock. The results of this study were obtained through the field tests performed according to the UNE EN 13829 Standard in a determined sample at a 95% of confidence and a 10% of error. These parameters are highly acceptable considering the existing unawareness and uncertainty levels in Chile prior to the performance of this study. The compliance of the minimum representative sample of 135 units was achieved by the performance of 191 tests.

The on-site test results were statistically analyzed with different techniques in order to establish the most influential factors in building behaviour related to airtightness. The general analysis determined the existence of statistically significant evidence for the creation of an infiltration baseline for Chile. The analysis of the different factors related to airtightness showed that the predominant material of walls is the most suited variable for the creation of the baseline because of the greater differences observed. Consequently, the air infiltration baseline is established by the predominant material of walls, with the following n50 values: concrete=9.0 ach; brickwork=11.8 ach; brickwork plus lightweight structure=15.0 ach; timber=24.6 ach; other materials=10.2 ach.

The baseline allows the observation of the current state of the Chilean housing airtightness characteristics. It mainly serves the purpose of creating future guidelines that regulate and limit the air permeability of dwellings and contribute to diminish their energy consumption.

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