THE ENERGY IMPACT OF ENVELOPE LEAKAGE. THE CHILEAN CASE

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ABSTRACT

Improving the airtightness of housing is an issue that concerns the Chilean state. Building ordinances do not currently include any requirement to limit infiltration and its associated energy loads. This situation affects the energy and environmental performance of housing, and has economic and social consequences of great importance for inhabitants and the State. This text presents part of a research project commissioned by the Chilean Ministry of Housing and Public Works, with the aim of defining acceptable airtightness standards for buildings by territorial zone in Chile. The results are presented of a baseline study intended to measure the impact of infiltration on the energy demand for the thermal conditioning of dwellings in Chile.

Using pressurization techniques, air tightness was measured in a sample of 185 dwellings built in 2007 and 2010, which is representative of more than 95% of the construction carried out in those years in the 54 provincial capitals of Chile. The LBL model was used to link airtightness properties of dwellings with climate variables in each of the provinces to obtain standardized coefficients of infiltration. Finally, with the dynamic simulation software TAS, energy loads due to infiltration and total energy demand were measured by building type and province.

It was concluded that the energy loads caused by infiltration in Chile vary significantly and have different effects depending on the type of energy demand. In particular, in the sectors with predominant heating needs, air infiltration generates demands of between 23 and 203 kWh/m².year, and can represent between 20 and 50% of the total energy demand for thermal conditioning. Also, it was confirmed that in the country's current state of development, an important step in the energy improvement of the building stock necessarily lies in the improvement of its airtightness characteristics.

KEYWORDS

Air infiltration; Airtightness; Energy efficiency of buildings

1 INTRODUCTION

Through an agreement signed by the National Commission for Scientific and Technological Research CONICYT, the University of the Bío-Bío and the Pontifical Catholic University of Chile, it was agreed to carry out FONDEF project D10R1025, "Establishment of acceptable kinds of building infiltration for Chile", with an implementation deadline of 30 months starting in December 2011. This work was commissioned by the Chilean Ministries of Housing and Urban Development and Public Works.

The project was submitted to the XVIII FONDEF Projects Competition by a technology consortium, under the mandate of the Chilean Ministries of Housing and Urban Development, and Public Works. The technology consortium in charge of its execution and transfer is comprised of: the Technical Division of Housing Development and Study (DITEC) at the Ministry of Housing and Urban Development; the Directorate of Architecture at the Ministry of Public Works; the Chilean Energy Efficiency Agency at the Ministry of Energy; the School of Civil Construction at the Pontifical Catholic University of Chile and its Directorate of Outreach in Construction (DECON UC); the Center for Research in Construction Technologies at the University of the Bío-Bío (CITEC UBB); the Catholic University of Louvain in Belgium; the Technology Resource Center in France (NOBATEK); and the Pocuro S.A., Venteko S.A., Indalum S.A., Alcorp S.A. and Wintec S.A. construction companies.

The Fondef Project proposed the development of standards for airtightness and acceptable kinds of building infiltration by territorial zone in Chile, with the aim of reducing to acceptable limits the impact of air infiltration on energy demand and consumption in the building industry. In addition, it involved the development of knowledge and technological solutions to support the design, implementation and quality control of projects, in order to obtain buildings with airtightness levels adjusted to minimum optimum energy use needs throughout the nation (CITEC UBB & DECON UC, 2010).

This report, part of Fondef Project D10I1025, presents the results of a baseline study designed to measure the current impact of air infiltration on the energy demand for the thermal conditioning of dwellings in each of the 54 provinces of Chile. This knowledge is necessary to define criteria to establish kinds of airtightness and to understand gaps in quality by building type and Chilean province.

2 DESCRIPTION OF THE PROBLEM

Air infiltration, is defined as the passage of uncontrolled air through hidden cracks and unplanned openings in the envelope. It generates thermal loads, due to cold or heat depending on the season, which affect a building's energy performance, and also transport noise and air pollutants that affect environmental comfort (Liddament, 1996). It is produced by pressure differences that induce flow through the envelope. These are caused by wind action, indoor-outdoor temperature differences, or by the operation of mechanical ventilation equipment.

Chile is located between 17°30' south and the South Pole, primarily in the temperate and polar zones of the southern hemisphere. Because of its size, location and geographical configuration, it has a great variety of climates and micro-climates. More than 80% of the

population is located in the central and southern parts of the country where the energy demands for the thermal conditioning of buildings are mainly for heating.
Thermal regulations, which are intended to establish energy savings objectives and requirements for residential buildings in Chile, are under construction. Newly created in the year 2000, the regulations establish seven thermal zones differentiated by heating degree days, and for each, set only thermal insulation requirements. At present, different activities are being carried out including the Fondef project mentioned above, which aim to define the requirements necessary to regulate other important matters, such as airtightness and ventilation, with the purpose of improving the construction ordinance in the areas of energy and environment. This is nowadays esteemed to be essential in reducing the energy demand of buildings in Chile to acceptable limits (Bobadilla, 2014).

In the last decade, regulations have been able to limit transmission losses through building envelopes, but have not produced significant results in the energy improvement of buildings, as demonstrated by several recent studies (Damico *et al.*, 2012; Escorcia *et al.*, 2012). The most consistent explanation attributes this fact to the reduced ability of buildings in Chile to resist air infiltration.

A baseline study of air infiltration, also carried out in the context of Fondef Project D10I1025, found that the average airtightness of the new housing stock in Chile, its n50 value, is located at the level 12.9 1/h (Bobadilla *et al.*, 2014; Figueroa et al., 2013). Average values for stock are expected to be in the range of between 11.1 and 14.7, at 95% confidence level. These indicators are enlightening in regards to the degree of airtightness in buildings in Chile and the current state of development of design and building techniques. However, they are also indicators of the energy efficiency of the stock. Less than 5% of stock meets the 3.0 1/h standard reference limit of airtightness that is in effect in several European countries. Particularly critical is the standard in timber construction, which presently exhibits airtightness indices around 24.6 1/h. All of these indicate the absence or deficient use of sealing techniques, as well as poor implementation quality, which should be improved to ensure the acceptable energy performance of the building stock in Chile.

Alternately, case studies showed that air infiltration can come to represent 60% of energy demand in some areas (Ossio *et al.*, 2012). This situation plays a key role in the energy and environmental performance of dwellings, in the quality of life of the population and, to a significant degree, in energy costs, which have economic and social consequences of great importance for the population, industry and State of Chile.

The acceptable type of airtightness defines in practice what society accepts as the maximum permissible heat loss in an area or country due to air infiltration. In accordance with international practice, the standard is set by attempting to successfully combine at least two criteria: that the type is such that at least a percentage of the building stock complies and; that energy demand attributed to infiltration does not exceed a certain value (ASHRAE, 2004). It is this context that justified this investigation, which aimed to establish the energy impact of air infiltration on new building stock in Chile. The results are presented in this report.

3 METHODOLOGY

For research purposes, the target population was defined as all dwellings with building permits requested in 2011, distributed throughout the 54 provinces of Chile. The universe included 151,071 housing units, which have a combined floor area of 10,431,888 m². From this universe, a sample of 185 dwellings was selected. This was representative of more than

95% of the construction undertaken that year in Chile and had a sampling error of 10%. The sample was defined considering features of interest, such as the predominant material in walls (concrete; brickwork; brickwork plus lightweight structure; timber; other materials) and the type of grouping (detached, semi-detached and row houses). In this way, 20 distinct building types were obtained in the 54 provinces, which are detailed in Table 1.

The investigation involved the following activities:

- Measurement of the sample
- Dynamic Simulation

Table: 1 Housing types that make up the sample. Source: CITEC UBB & DECON UC, 2013.

Code	Description	Surface (m²)
T1	House - brickwork - one floor - detached	67
T2	House - brickwork - one floor - row houses	67
T3	House - brickwork - two floors - detached	75
T4	House - brickwork - two floors - row houses	75
T5	House - concrete - one floor - detached	66
T6	House - concrete - two floors - detached	66
T7	Apartment building - brickwork and/or concrete	46
T8	House - concrete blocks - one floor - detached	50
T9	House - concrete blocks - two floors - detached	75
T10	House - concrete blocks - two floors - row houses	75
T11	House - timber - one floor - detached	50
T12	House - timber - one floor - row houses	50
T13	House - timber - two floors - detached	80
T14	House - timber - two floors - row houses	80
T15	House - SIP - one floor - detached	66
T16	House - other materials - one floor - detached	66
T17	House - other materials - two floors - detached	75
T18	House - other materials - two floors - row houses	75
T19	House - brickwork plus lightweight structure - two floors - detached	75
T20	House - brickwork plus lightweight structure - two floors - row houses	75

3.1 Measurement of the sample

The Blower Door pressurization technique was used as described in the standard UNE -IN 13829 "Thermal performance of buildings -- Determination of air permeability of building -- Fan pressurization method", to measure air permeability, and with it the airtightness of the housing sample. This physical property was synthesized with the indicator air changes per hour, 1/h, measured at 50 pascals of pressure difference.

Table 2 shows the results obtained. A considerable difference was observed in airtightness properties when the different materials categories were compared; the average n50 value of the sample was determined to be 12.9 1/h, with minimum values of 2.6 1/h and a maximum of 49.8 1/h.

Table: 2 Summary of Study Results, Method A. Source: Figueroa *et ál*, 2013.

Predominant Material in Walls	Minimum n50 value (1/H)	Maximum n50 value (1/h)	Average n50 value (1/h)
Concrete	2.6	28.6	9.0
Brickwork	4.3	19.6	11.8
Brickwork plus Lightweight Structure	2.3	49.2	15.0
Timber	4.5	49.8	24.6
Other materials	3.3	15.7	10.2

3.2 Dynamic Simulation

The energy modeling software *TAS* version 9.2.1.4 was used to determine energy loads from infiltration and the total demand of dwellings, including the distinct building types present in the 54 provinces of Chile.

It was necessary to create new meteorological databases to cover the entire nation and make improvements to the existing databases. The new databases include time information for weather variables in the 54 provincial capitals of Chile and were obtained through a process of adaptation and validation of the databases that the software *Meteonorm* 6 generates. The adjustment method used at the University of Southampton (Hampton *et al.*, 2013), originally applied to correct the effects of global warming on weather databases, was employed in the correction and adaptation of data. This methodology made it possible to modify the time data of the *Meteonorm* databases, so as to coincide with official monthly information and other specific local sources (Gonzalez *et al.*, 2013).

The thermal properties of the dwellings were deduced from the plans and technical specifications for the housing projects. To consider air infiltration, standard coefficients of infiltration were determined for the distinct dwellings in each of the provinces using the LBL model developed at the Lawrence Berkeley Laboratory (Sherman & Modera, 1986). These coefficients of infiltration linked the typical airtightness properties of the envelope of each building type (determined in 3.1) with local climate variables. This was used to measure the energy load from air infiltration with the energy simulation program TAS.

4 RESULTS

4.1 . Standardized coefficients of infiltration

In 14 of the 54 provinces, the standardized coefficients of infiltration are less than or equal to 1 1/h, within the range 0.7 -1.0 1/h. They are associated with inland locations, mainly in the north central area of the country, some of which have micro-climates, average wind speeds under 2.5 m/s and several months officially designated as calm weather (less than 2.0 m/s). These localities are also compatible, in some cases, with relatively high average exterior temperatures, which minimize the effects of thermal draft. The greatest weighted provincial values are in the range of 1 and 2.9 1/h and are associated with coastal localities, mainly in the southern and austral areas, with annual average speeds greater than 2.5 m/s and/or low average temperatures. Variations in standardized infiltration by building type and province are quite a bit larger. They range from 0.4 1/h for a detached, 1-floor, block concrete dwelling in the city of Vallenar (annual average wind speeds less than 2.0 m/s and an average temperature of 14.9 ºC), to 4.0 1/h for a detached, 1-floor, wood construction in Punta Arenas (mean annual wind speed of 8.2 m/s and an average temperature of 5.9 °C).

4.2 Energy demand by building type and province

Table 3 shows energy demands by building type present in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas. Heating, cooling, and total demands are given considering the load associated with the standard infiltration of each building type in the province, which are also listed. The table also includes the weighted demands by province (Depp), which are an indicator that takes into consideration the participation, by built surface area, of the different building types in the housing stock.

Table: 3 Energy demand of residential buildings in the provinces of Antofagasta, Santiago, Concepción and Punta Arenas. Source: Bobadilla, 2014.

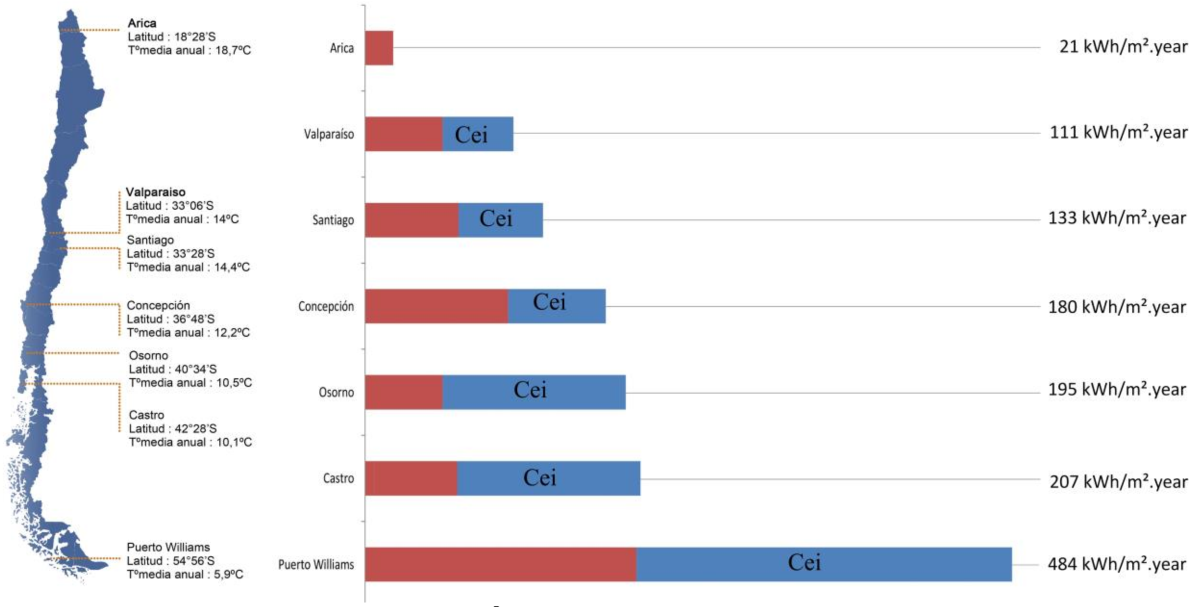
Parám.	**PROVINCES - BUILDING TYPE**																		
	Antofag.		**Santiago**			**Concepción**							**Punta Arenas**						
	T6	**T7**	**T3**	**T6**	**T7**	**T3**	**T6**	**T7**	**T11**	**T13**	**T17**	**T19**	**T11**	**T13**	**T12**	**T14**	**T17**	**T18**
ln	1.3	1.0	0.9	0.9	1.6	1.4	1.5	2.6	2.3	2.7	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dett	120	89	145	147	131	175	160	186	231	210	225	236	511	455	585	439	406	307
Depp	92		134			207							449					

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

Tables 4 and 5 present the weighted provincial energy demands by built surface area, of the main building types present in the various provinces. Demands were measured with infiltration coefficients of 0 (1/h) and the corresponding standardized coefficient Ln (1/h).

An example of the results is shown in Figure 1, where 7 provinces are represented and the contribution of air infiltration to energy demand is noteworthy.

Figure: 1 Weighted energy demands by provincial capital with energy load from infiltration.
Source: Bobadilla,
2014.



Cei : Energy load from infiltration (kWh/m^2.year)

These tables were used to create the provincial map of energy demands for the thermal conditioning of housing stock with 2011 building permits in Chile. At this level, the predominance of heating needs in residential buildings in Chile can be observed. In 21 of the 54 provinces only heating needs are reported. 31 provinces present combined heating and cooling demands. In 18 of these, cooling demands do not exceed 15 kWh/m². year; in 2 they do not exceed 28 kWh/m².year; and in 2 there are only cooling requirements. These are mostly concentrated in the provinces in the north and some in the center of the country, including Santiago.

Heating requirements are present in virtually the entire nation, mainly in the Andean area and center south of the country. In 45 of the 54 provinces, the demand exceeds 100 kWh/m².year; in 15 provinces it exceeds 200 kWh/m².year; and in 4 provinces it exceeds 400 kWh/m².year. These are all indicators that reflect a low level of energy quality in the new building stock in Chile.

The energy load due to air infiltration varies significantly and has a different impact depending on the type of energy demand. In the provinces with predominant heating needs (Only heating is required or cooling demand does not exceed 10% of heating.), infiltration means demands of between 23 and 203 kWh/m².year, which may represent between 20 and 50% of the total energy demand for thermal conditioning.

Table: 4 Weighted energy demands by provincial capital - North and Center. Source: Bobadilla, 2014.

Zone	Province	Det_o	ln	Detp	Decp	Derp	Cei
17°35'S	**Arica**	19	1,3	21	0	21	-3
	Putre	135	1.5	209	209	0	74
	Iquique	21	1.2	28	20	9	7
	Pozo Almonte	297	1.5	378	367	10	81
N	**Tocopilla**	12	0.9	11	0	11	-1
O	**Calama**	137	2.8	269	259	9	132
R	**Antofagasta**	70	1.0	93	79	14	23
T	**Chañaral**	54	1.0	60	49	11	6
H	**Copiapó**	75	1.7	104	76	28	29
	Vallenar	74	0.7	92	81	11	18
	Coquimbo	91	1.4	133	122	11	42
	Ovalle	79	1.5	113	93	20	34
31°46'S	**Illapel**	127	0.7	168	143	26	41
32°15'S	**La Ligua**	90	1.1	124	100	23	34
	Los Andes	74	1.9	138	116	22	64
	San Felipe	109	1.3	152	119	33	43
	Quillota	113	0.9	151	133	18	38
	Valparaíso	53	2.2	111	111	0	58
	San Antonio	73	2.1	119	119	0	46
	Hanga Roa	34	1.0	35	1	33	1
	Quilpué	51	1.5	110	110	0	59
	Colina	106	0.9	140	124	16	34
	Santiago	77	1.5	133	119	14	56
C	**Puente Alto**	103	0.8	134	117	17	31
E	**San Bernardo**	98	0.9	148	134	14	50
N	**Melipilla**	109	0.9	130	109	21	21
T	**Talagante**	114	1.1	160	149	10	46
E	**Rancagua**	92	0.9	113	103	10	80
R	**San Fernando**	109	0.9	137	126	11	94
	Pichilemu	78	1.0	96	96	0	23
	Curicó	106	1.0	141	132	9	33
	Talca	87	1.1	129	112	17	131
	Linares	111	0.7	133	123	9	22
	Cauquenes	99	1.6	159	143	16	60
	Chillán	89	1.3	142	133	9	53
	Los Ángeles	91	1.2	150	136	14	59
	Concepción	73	1.7	180	180	0	107
38°20'S	**Lebu**	79	2.3	197	197	0	118

Det_0 : Total provincial energy demand without infiltration (kWh/m ^{2}.year)
ln : Standardized infiltration coefficient (1/h)
Detp : Total energy demand with standardized provincial infiltration (kWh/m ^{2}.year)
Decp : Provincial energy demand for heating (kWh/m^2.year)
Derp : Provincial energy demand for cooling (kWh/m^2.year)
Cei : Energy load from Infiltration (kWh/m^2.year)

Table: 5 Table: 6 Weighted energy demands by provincial capital - South and Austral. Source: Bobadilla, 2014.

Zone	Province	Det_0	In	Detp	Decp	Derp	Cei
37°40'S	**Angol**	75	1.2	110	104	6	35
	Temuco	155	0.8	202	202	0	47
S	**Valdivia**	117	1.0	171	170	0	54
O	**La Unión**	108	1.0	154	154	0	46
U	**Osorno**	137	1.1	195	195	0	58
T	**Puerto Montt**	137	1.3	192	192	0	55
H	**Castro**	145	1.2	207	199	7	62
43°37'S	**Chaitén**	155	1.0	201	201	0	46
44°45'S	**Coyhaique**	181	1.5	264	264	0	83
A	**Puerto Aysén**	161	1.6	260	260	0	99
U	**Chile Chico**	187	2.9	364	364	0	177
S	**Cochrane**	117	2.7	227	227	0	110
T	**Puerto Natales**	221	1.7	325	325	0	104
R	**Punta Arenas**	213	2.8	446	446	0	233
A L	**Porvenir**	199	1.2	277	277	0	78
54°56'S	**Puerto Williams**	281	2.1	484	484	0	203

Det_0 : Total provincial energy demand without infiltration (kWh/m ^{2}.year)
ln : Standardized infiltration coefficient (1/h)
Detp : Total energy demand with standardized provincial infiltration (kWh/m^2.year)
Decp : Provincial energy demand for heating (kWh/m^2.year)
Derp : Provincial energy demand for cooling (kWh/m^2.year)
Cei : Energy load from infiltration (kWh/m^2.year)

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

The localities that demand the most energy are: Puerto Williams, Punta Arenas, Puerto Natales, Chile Chico and Pozo Almonte, all of which have weighted provincial demands greater than 325 kWh/m².year. In contrast, the localities with the least energy demand are: Arica, Iquique and Tocopilla, with values below 28 kWh/m².year, corresponding to only cooling demands. In the provinces where cooling needs predominate (Only cooling is required or heating demand does not exceed 10% of cooling.), in 4 of the 54 provinces of Chile, infiltration helps to reduce energy use.

Dwellings located in localities in the Andean zone, which runs from the north to the south of the country, present demands above 200 kWh/m².year. These are high but expected considering the harsh climate of this area and the typically low levels of thermal protection in the buildings in this territory. From north to south in inland areas, progressive demands can be observed in general terms, ranging from a bit more than 10 KWh/m².year in Arica and Tocopilla (cooling), up to more than 400 KWh/m².year in Punta Arenas and Puerto Williams (heating), which are explained in the same way.

5 CONCLUSIONS

Improving the airtightness of housing is an issue that concerns the Chilean state. Building ordinances do not currently include any requirement to limit infiltration and its associated energy loads. This situation affects the energy and environmental performance of housing, and has economic and social consequences of great importance for inhabitants and the State.

In the current state of development, an important step in the energy improvement of the building stock in Chile is, necessarily, to improve its airtightness characteristics. The baseline of airtightness in buildings completed between the years 2007 and 2010 is 12.9 1/h, with expected values between 11.1 and 14.7 1/h with 95% confidence. This is an overall measure of the current techniques used and quality associated with sealing and airtightness of residential buildings in Chile. Especially critical is the standard of airtightness in timber construction, which has indices around 24.6 1/h. All of these indicate the absence or deficient use of sealing techniques, as well as poor implementation quality, which should be improved in Chile to ensure the acceptable energy performance of all building types constructed in Chile.

The standardized coefficients of infiltration range from 0.7 to 2.9 1/h throughout the nation. The lowest values are associated with inland locations, mainly in the north central area of the country, some of which have micro-climates, that are compatible with low average wind speeds and/or relatively high average exterior temperatures. Meanwhile, the highest standardized coefficients of infiltration are associated with coastal localities, mainly in the southern and austral areas, with wind speeds over 2.5 m/s and/or low average exterior temperatures.

The results of the dynamic simulations show that energy loads due to infiltration in Chile vary significantly and impact in different ways depending on the type of energy demand. In particular, in the sectors with predominant heating needs, air infiltration generates demands of between 23 and 203 kWh/m².year, and can represent between 20 and 50% of the total energy demand for heating and cooling.

All regulation that seeks to organize and regulate construction should be based on actual physical data so that its dictates are effectively feasible. For these purposes, this research delivers important references in order to understand and reduce gaps in quality in terms of sealing and airtightness of buildings in Chile, and criteria for the establishment of airtightness requirements, an undertaking that is currently in progress in Chile.

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