Recibido 29/08/2020
Aceptado 16/12/2020

PREFABRICATED BUILDINGS IN CHILE: ENERGY DIAGNOSIS, 40 YEARS AFTER THEIR CONSTRUCTION. CASE STUDY: KPD BUILDINGS, SANTIAGO DE CHILE.

EDIFICIOS PREFABRICADOS EN CHILE: DIAGNÓSTICO ENERGÉTICO A 40 AÑOS DE SU CONSTRUCCIÓN. CASO DE ESTUDIO: EDIFICIOS KPD, SANTIAGO DE CHILE.

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RESUMEN

Los edificios KPD son construcciones habitacionales sencillas y discretas, pero emblemáticas en Chile. Su recorrido histórico por este país inicia con un terremoto y se entrelaza con los antagónicos gobiernos de Salvador Allende y Augusto Pinochet. Estas construcciones han permanecido ajenas a las actualizaciones de la reglamentación térmica, pasando a formar parte del extenso parque habitacional construido que necesita ser diagnosticado energéticamente, para alinearlo a las exigencias térmicas nacionales y, de ese modo, mejorar la calidad de vida de sus habitantes y aportar a la carbono-neutralidad ya comprometida por Chile. Este artículo presenta un estudio de caso de evaluación de confort térmico en un conjunto habitacional de edificios KPD, ubicado en la Región Metropolitana. En concreto, se analizan cuatro edificios, idénticos en materialidad y distribución, pero con diferentes orientaciones. La metodología de evaluación consideró un triple enfoque: normativo, de etiquetado y subjetivo; e involucra a los habitantes en el diagnóstico, quienes constante e inexplicablemente, han quedado marginados en el análisis de sus propias viviendas. Los resultados del estudio han evidenciado discrepancias entre la percepción de los residentes y el rango de confort que utiliza la calificación energética nacional vigente.

Palabras clave
confort térmico, etiquetado energético, vivienda social

ABSTRACT

KPD residential buildings, although simple and discrete, are emblematic of Chile. Their story in this country starts with an earthquake and is intertwined with the antagonistic governments of Salvador Allende and Augusto Pinochet. These buildings have remained outside current thermal regulations, and have become part of an extensive built housing stock that need to be diagnosed in terms of energy, to align them with domestic thermal requirements and, in this way, improve the quality of life of their inhabitants and contribute to what Chile has already committed to in terms of carbon neutrality. This article presents a thermal comfort evaluation case study of a KPD residential building complex in the Metropolitan Region. Concretely, four buildings are analyzed, each with the same materials and distribution, but with different orientations. The evaluation methodology considered a three-fold approach: regulatory, labeling and subjective and involved their inhabitants in the diagnosis, who had constantly and inexplicably been marginalized in previous analyses of their own homes. The results show discrepancies between the residents' perception and the comfort range used by the current energy rating system in Chile.

Keywords
thermal comfort, energy labeling, social housing

INTRODUCTION

The history of KPD in Chile begins on July 8th 1971, during the government of President Salvador Allende, the day the country was hit by a 7.7 earthquake on the Richter scale that destroyed more than 20,000 dwellings. As a result, the former Soviet Union donated to the country a prefabricated concrete panel plant, including machinery and technical support. The factory was set up in Quilpué and was called K.P.D. (KrupnoPanelnoyde Domostroyenie) which means "Large Concrete Panel" in Russian.

The Russian technicians worked in the startup and training of Chilean workers, as such "from a technical point of view, the plant constituted for Chile a unique experience on being an advanced heavy prefabrication that incorporated new production and assembly technologies with a high percentage of mechanization and automation (Bravo Heitmann, 1996, p. 14).

In this way, KPD became the largest heavy prefabricated housing industry in the country, capable of producing 2,000 dwellings a year, as the concrete panels integrated all the ducts and anchoring points within their components for their onsite assembly.

When the Coup d'état took place in 1973, the plant was raided, the Soviet technicians were deported and Chilean staff, fired. The latter were later rehired, as they were the only ones trained to make the factory work, which was renamed VEP, Viviendas Económicas Prefabricadas El Belloto (or El Belloto Economic Prefabricated Dwellings), working until 1981. In total, 153 apartment buildings were built, located in Viña del Mar, Quilpué and Santiago (Brignardello Valdivia, 2017).

On the other hand, currently residential energy consumption in Chile, considering the end use that is given to energy, determines that 53% is destined for heating and air-conditioning (Technical Development Corporation, In-Data – CDT, 2019), as such it is not strange that the "Roadmap" set out by the Energy Ministry detects as a gap in the residential sector that, "The energy comfort level, mainly regarding the thermal quality experienced in buildings, is low or non-existent. Thus, due to this, energy consumption in buildings in the country is inefficient" (Ministry of Energy, Government of Chile, 2015, p. 48). The European Climate Foundation, in their latest study, suggest that, to achieve 100% decarbonation of the residential construction sector, policies are needed in five areas, the first being an improvement in the envelope of new and existing buildings (CE Delft, 2020), which is why conditioning this housing stock becomes a priority in the country agenda to comply with the agreements made in the recent COP25, where Chile voluntarily agreed to carbon neutrality by 2050 (United Nations Climate Change, 2019).

These emblematic buildings are part of the 67% of dwellings built before 2000, when Chile did not have a thermal conditioning regulation (Energy 2 Business SpA, 2020, p. 55). As such, making a diagnosis of their energy performance becomes relevant inasmuch as it contributes to show the thermal comfort problem that affects the country's social housing.

DESCRIPTION OF THE PROBLEM

A dwelling must offer the inhabitant inhabitability and indoor comfort conditions. However, this is not an isolated element, since it falls within a place, with a given climate and geography, where constructions and neighboring activities also interact and can condition our comfort and the inhabitability of said dwelling.

The description of comfort is broad and has several discrepancies. For this study, "thermal comfort" is considered as the state that describes a balance of environmental and personal factors that make a person feel satisfied and comfortable in their thermal environment (Nicol & Roaf, 2017).

Thermal comfort goes beyond mere satisfaction: the indoor temperature of a dwelling must be sufficient to protect residents from harmful effects for their health. In countries with template or cold climates, 18°C has been proposed as a safe and well balanced indoor temperature to protect the health of the general population during cold seasons (World Health Organization [WHO], 2018). This is related to what is stated by Howden-Chapman, Roebbel and Chisholm (2017), who confirm that cold homes contribute to excess winter mortality and to morbidity from respiratory and cardiovascular diseases. Other authors add mental health to this, as the combination of economic restrictions and cold and wet living conditions lead directly to physical health and stress issues, which once activated, together with anxiety and the distortion of moods, operate globally, affecting immune, cardiovascular and hormonal functions (Liddell & Guiney, 2015).

Contrary to what may appear at first glance, having cold dwellings is not exclusive to severe climates. This can be seen in the article of Daniel, Baker and Williamson (2019) contextualized in Australia, which states that, although outdoor temperatures are far from being extremely cold, indoor temperatures are found to be below standard and unsatisfactory for occupants who, most of the time, wanted higher temperatures in their home. This situation is repeated in the south of Spain, where three social multi-family dwellings built before the thermal regulations were monitored, showing similar results, with over 90% of hours outside the comfort range (Escandón, Suárez & Sendra, 2017).

As a result, there is a two-fold issue: on one hand, an elevated energy consumption to maintain comfort temperatures in deficient dwellings and, on the other, dwellings outside comfort ranges due to families living there not being able to afford this expense. Both situations have negative repercussions on society, whether generating emissions above acceptable limits, or harming the health of inhabitants, which have an impact on already overstretched health facilities.

STATE-OF-THE-ART

New housing is a constant demand. In fact, it is estimated that a billion new dwellings are needed around the world for 2025 (United Nations Human Settlements Program, UN-Habitat, 2016). This is added to the need to reduce and optimize energy consumption. It is for this reason that countries around the world have been implementing obligatory thermal regulations for several years now and numerous energy certifications abound for new homes, also incorporating passive strategies in the design, all seeking greater efficiency. Existing dwellings must also align with this scenario.

LEGAL FRAMEWORK IN CHILE

In thermal regulations matters, the General Ordinance of Urbanism and Constructions, hereinafter OGUC (Government of Chile, 1992), sets the requirements for opaque and translucent envelopes, and organizes the country into thermal zones. The zoning that OGUC refers to is a thermal zoning, based of heating-day degrees (Ministry of Housing and Urbanism [MINVU] and Construction Institute, 2006, p.8)

These requirements, indicated in Article 4.1.10 have been progressive: the first was established in 2000, where the obligation of thermal insulation in the roof was defined; then, in 2007, requirements for the rest of the envelope were incorporated, covering walls, ventilated floors and windows. In November 2015, Article 4.1.10 Bis was added, which establishes that the Atmospheric Decontamination and/or Prevention Plans prevail over the Ordinance. These plans are environmental management instruments whose purpose is to reduce contamination levels. Currently, there are 15 plans in force in Chile, 10 of which consider improvements of the thermal efficiency of dwellings, which is why their requirements go beyond those ruled by the OGUC (Ministry of Environment, 2020).

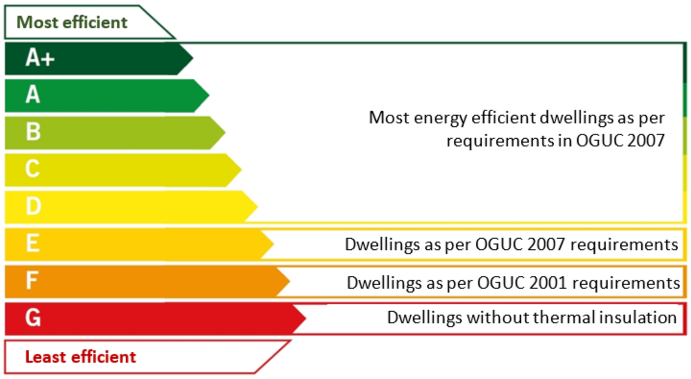


Figure 1. Figure 1. Relationship between CEV labels and the national thermal regulation.Source: Preparation by the authors based on the CEV Manual (MINVU, 2019).

As for existing dwellings and regulatory issues, the aforementioned requirements only apply for extensions, as on processing a building permit it is necessary to present to the respective municipality, the compliance accreditation form for Thermal Conditioning regulation AT-01, where the requirements to be met by the envelope considering the thermal zone and the construction solutions used for this are outlined, attaching the calculations, test certificates, datasheets and plans that apply.

DWELLING ENERGY RATING (CEV)

The Dwelling Energy Rating, hereinafter CEV, is an instrument developed by the Ministry of Housing and Urbanism together with the Ministry of Energy. It has been in force since 2012 and today is in version 2.2.

The CEV is designed for the national territory, is applicable to new and existing dwellings and defines itself as an "objective and standardized assessment that allows knowing and optimizing the energy requirement of a dwelling" (MINVU, 2019). It seeks that energy efficiency is transformed in an important factor for supply and demand in dwellings, through an attractive language for the end consumer.

The CEV issues an energy rating report and an energy efficiency label that provides, among other things, the following indicators:

- Heating consumption and demand [kWh/m^2 year],
- Cooling consumption and demand [kWh/m^2 year],
- Hours of discomfort, above and below the comfort range (HD(+-)), [h]

The labels have eight levels, from "A+" to "G", which are linked to the stages of the domestic thermal regulation, as can be seen in Figure 1.

These labels are the result of a theoretical estimation of energy requirements for heating, cooling, sanitary hot water and lighting of a dwelling in Chile. In this framework, the CEV system works with dynamic thermal balance spreadsheets called PBTD, which make a thermal balance every 60 seconds, evaluating the temperature inside the premises, based on the flows of the different entry variables.
The variables considered are:

- Internal loads: these correspond to tabulated powers.
- Radiation: climate data of the zone, which considers nearby and distant obstructions.
- Envelope: this corresponds to the heat transfer associated to this.
- Leaks: these correspond to tabulated air renewals because of leaks (RAH) (University of Bio-Bio, Construction Technologies Research Center – CITEC-UBB, Construction Direction, DECON UC 2014).
- Ventilation: air renewals per hour or ventilation rate.
- Thermal bridges: These correspond to [U] transmittance coefficients associated to different thermal bridges.
- Thermal inertia: these correspond to values tabulated for different materials.

These elements are evaluated and compared with a reference dwelling rated with the letter E, which corresponds to the current construction standard, namely, regulated following OGUC. It is important to highlight that reference demands are different for single-family and multi-family dwellings, named houses and apartments, respectively.

DESIGN V/S OPERATION

Energy certifications and thermal reconditioning of dwellings have been implemented for some time now in different parts of the world, accumulating in this way, evidence and experiences that open the door for analysis and debate.

Along this line, Ramos, Gago, Labandeira and Linares (2015) state that in the residential area, conventional energy efficiency solutions like higher standards or building regulations, are not being effective, as this sector is increasing its consumption in most countries, which can be attributed to a problem of behavior and information. Onsite evaluations are finding differences of up to 2.5 times projected energy savings, so the economic approach of energy efficiency policies, that assumes these as beneficial investments that pay for themselves, is being questioned. The engineering models on which these policies are based are being contradicted by the evidence (Fowlie, Greenstone & Wolfram, 2015), especially when the building's energy consumption after occupation differs notably from the one designed. In this sense, many ecological buildings that save less energy than expected have been seen, from which it has been suggested that a clear relationship between real energy use and the certification level of buildings cannot be seen (Geng, Ji, Wa, Lin & Zhu, 2019).

THE USER FACTOR

A dwelling is an element designed by one person, but used by another and, from this point of view, the user experience regarding the operation of said dwelling is very relevant. When collecting information, the inhabitant can really say how the dwelling works in operation. However, this is rarely sought with these purposes, leaving this out of the evaluation of their own residence. In some case studies, it has been seen that to achieve comfort conditions, this depends, to a great extent, on the willingness and capability of users, which is why there must be a correct interaction between climate, building and users that is currently not being seen (Serghides, Dimitriou, Kyprianou & Papanicolas, 2017).

The leading role of user habits in the home's energy demand is a fact, with the inefficient handling of the systems being an important source of energy wastage (Cottone, Gaglip, Lo Re & Ortolani, 2015). This is why there needs to be a transfer of operational strategies by construction professionals to the inhabitant to reduce differences between a project's design and its later evaluation on being used. In fact, there are major opportunities in terms of energy performance and satisfaction with the indoor environment in personal control (Altomonte, Schiavon & Ken, 2019). In this context, the adaptive model would obtain the greatest advantages with user interaction (Bienvenido-Huertas, Rubio-Bellido, Pérez-Fargallo and Pulido-Arcas, 2020).

The importance of including inhabitants in the energy improvements of their dwellings is seen in a case study made in Mexico, which reveals that on facing new dwellings with insulation and energy efficiency improvements compared to others without these characteristics, the estimations foreseen in consumption reduction were not reached, which was assigned to human behavior. Hence, the urgency of incorporating this factor in the models used is seen (Davis, Martínez & Taboada, 2020). Education in energy matters is complex since differences are seen in the research made in energy literacy that impede making direct comparisons and that do not end up aiding political authorities in user education issues in domestic energy conservation and management (Van den Broek, 2019).

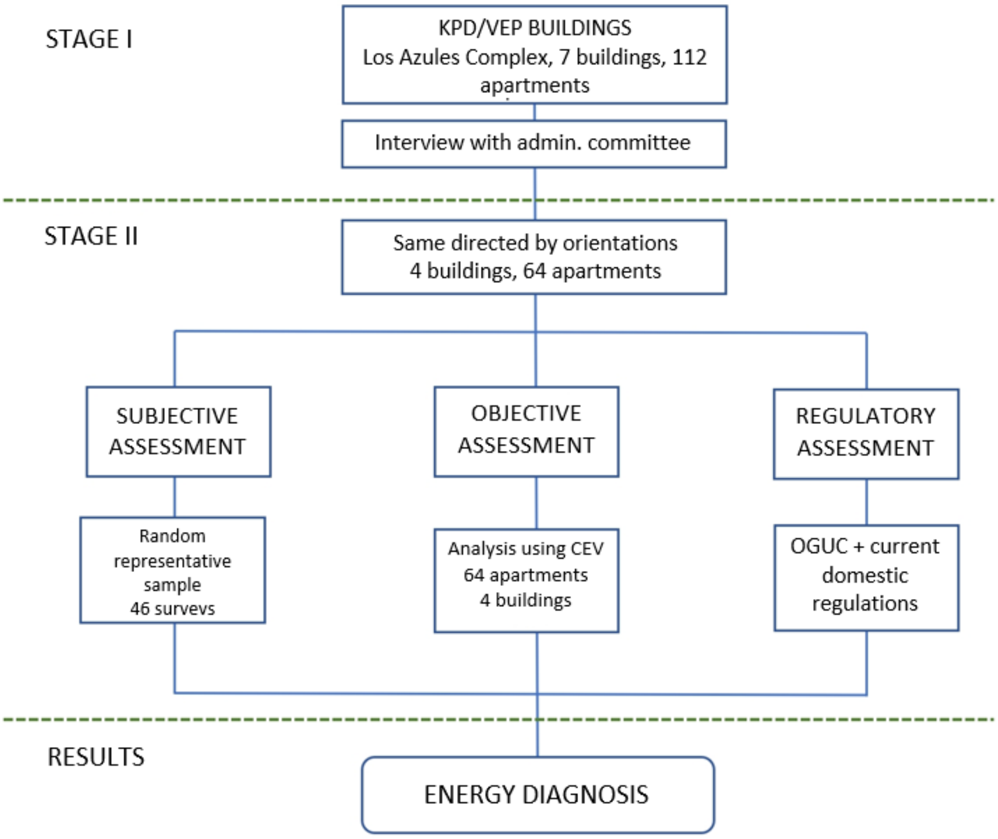


Figure 2: Diagnosis method flow chart. Source: Preparation by the authors.

It is also necessary to mention that there are discrepancies between surveys and monitoring processes, that try to write this off by a wrong location of sensors or due to temperature variations, which would cause a greater disconformity than expected (Diaz Lozano Vakalis, Touchiea, Tzekovac & Siegela, 2018).

METHODOLOGY

The diagnosis methodology, whose layout can be seen in Figure 2, considered two stages. The first stage corresponded to gathering technical information, for which a representative building was chosen, making an interview with the complex's administration committee, who provided initial information and, then, with the consultant, who provides complementary information. Once data was collected, the second stage began, which corresponded to a three-fold energy performance analysis: regulatory, which establishes the degree of compliance with OGUC and that involves checking the translucent and opaque envelope, where the current regulation to calculate transmittances is used (National Standards Institute [INN], 2007); of labeling, that uses the CEV tool and that allows evaluating the energy performance indirectly; and of perception, which makes it possible to include the inhabitants' point of view, which is relevant to show the coherence (or incoherence) of the energy rating tool's results. The thermal diagnosis of the housing complex was obtained as a result of this three-fold approach.

CASE STUDY

The complex subject of this study is called "Conjunto Los Azules". It was built in 1979 by VEP and is found in the Metropolitan region, in Santiago, in the commune of Macul.

TECHNICAL INFORMATION

LOCATION AND DISTRIBUTION

"Conjunto Los Azules" is located on Avenida Quilín, between Castillo Urizar and General Óscar Bonilla streets, in the commune of Macul in the city of Santiago de Chile and it comprises seven identical buildings. Figure 3 shows an overview of the complex.

Each building has four floors, a floor plan of 32x10 m and an approximate height of 12m, along with two staircases and four apartments per level, together totaling 16 apartments per building and 112 in total. The building's

Figure 3. Overview of the "Conjunto Los Azules" building complex. Source: Preparation by the authors based on Google Earth.

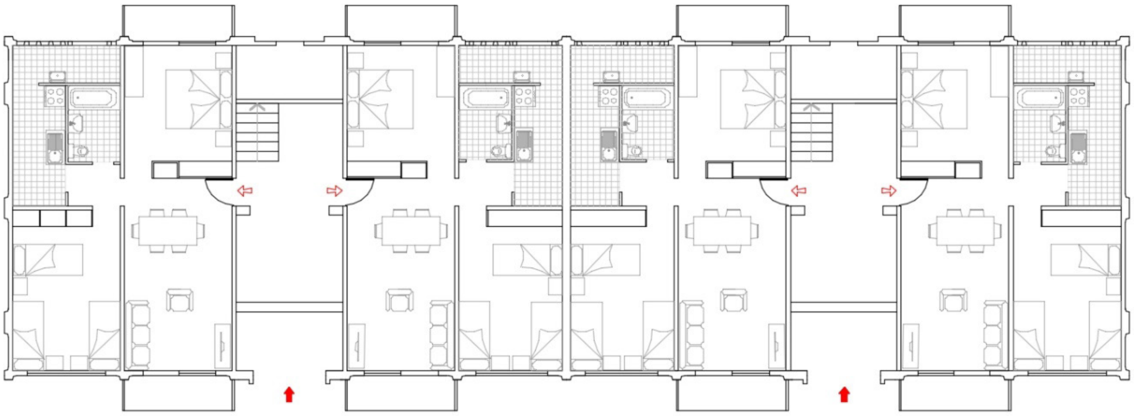


Figure 4. Distribution of the apartments, floor 1. Source: Preparation by the Authors

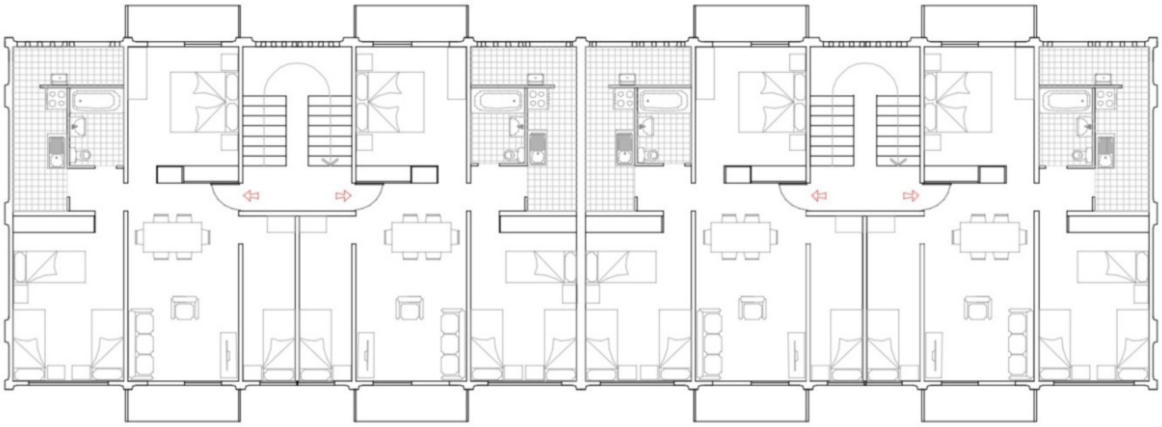


Figure 5. Distribution of the apartments, floors 2, 3 and 4.Source: Preparation by the Authors.

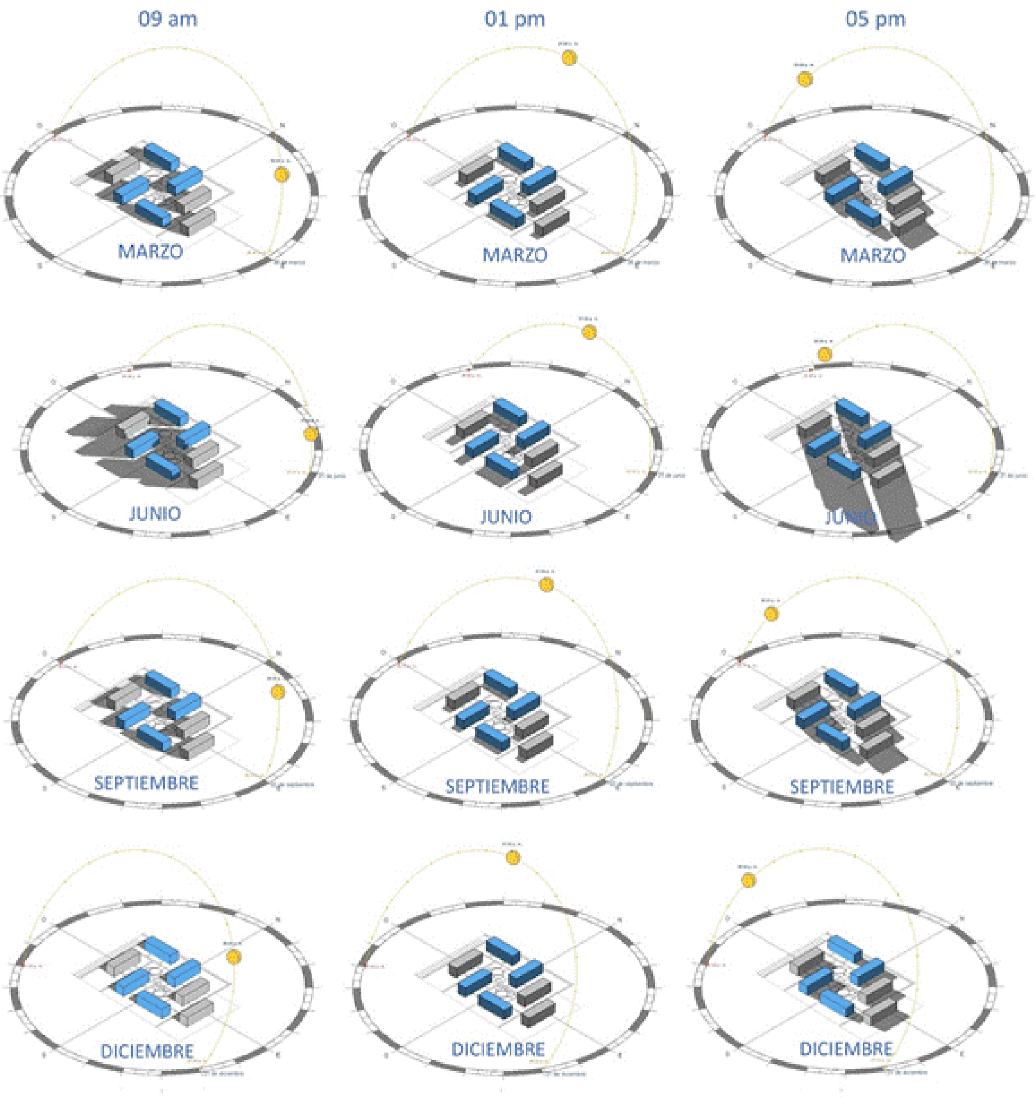


Figure 6. Solar path in the buildings analyzed, in the three times of the days and in the four seasons.Source: Preparation by the Authors.

floor plan distribution is presented in Figures 4 and 5. As can be seen, these apartments, on the first floor, are smaller as they include two bedrooms, unlike the upper floors that have three bedrooms each.

These buildings, although identical, vary in their orientation, as can be seen in Figure 3.

The study uses the façade of the dining room as the main one, on this being the one with the most exposed surface. As such, this determines the orientation of the buildings.

The orientation is, without a doubt, one of the main passive design strategies, which has an important influence on the project's cooling and heating energy demand. As an example, in this sense, from the building complex of this study, Figure 6 shows the annual solar path at three times of the day, for the four seasons of the year.

With the studied apartments being in the city of Santiago, the following was seen:

- North-facing: receives direct solar radiation during most of the day.
- South-facing: does not receive direct solar radiation most of the year.
- East-facing: receives direct solar radiation in the morning.
- West-facing: receives solar radiation during the afternoon.

It is worth noting that CEV analyzes solar radiations and possible obstructions to these, in two modalities: window accessibility factor (FAV in Spanish) that evaluates each one of them and their orientation, as well as the presence of obstructions nearby; and the accessibility factor regarding remote shading elements (FAR in Spanish), that evaluates the presence of remote obstructions for each façade. Both analyses are included in this research.

TECHNICAL SPECIFICATIONS

The data that needs to be considered for the thermal behavior study of the Prefabricated VEP Building are those corresponding to the configuration and materiality of their envelope.

- Walls: reinforced concrete prefabricated panel system. Concrete R28=200 kg/cm^2;
- Roof: 4th floor slab panels, on which structural 2" x 3" insigne pine trusses rest, with a 0.05m thick mineral wool thermal insulation;
- Floor: ventilated type. Its structure is formed by the slab panels of the 1st floor. This floor has an 8cm thick light concrete overlay;
- Windows: sliding type, with aluminum frame and monolithic glass.

RESULTS

REGULATORY APPROACH

The OGUC has requirements by thermal zone for the opaque and translucent envelope, not considering the buildings' orientation, which is why the analysis focuses on the construction typology, that is to say, not one building in particular, but rather all of them.

To check compliance of transmittances established in the opaque envelope, four methods can be chosen, which for an existing dwelling are reduced to two: test certificates of a recognized laboratory or calculation. In this study, calculations were used, made following NCh853-2007 Thermal conditioning – Thermal building envelope – Calculation of thermal transmittances and resistances (INN, 2007). In the case of the walls, three typologies were calculated, by thickness.

To check compliance of the translucent envelope, the demands vary depending on the type of glass involved, with these requirements being a maximum glazed surface percentage with respect to the envelope's vertical wall covering. This can be done using a direct calculation of surfaces or by weights; the latter are valid only in some thermal zones. Here a direct calculation was used.

The requirement for monolithic glass windows in zone 3 is 25%, a percentage that all the apartments assessed, met.

Table 1 summarizes the regulatory requirements and the situation of the complex studied.

Envelope elements	Regulatory Requirement	Situation assessed	Status
Walls	U ≤1.90 W/m2K	U = 4.70 W/m2K U = 4.11 W/m2K U = 3.68 W/m2K	Does not comply
Ventilated floors	U ≤0.70 W/m2K	U = 1.24 W/m2K	Does not comply
Roof	U ≤0.47 W/m2K	U = 0.70 W/m2K	Does not comply
Monolithic glass windows	Surface < 25% of vertical elements of the envelope	Less than 20%	Complies

Table 1. Regulatory assessment of the complex Source: Preparation by the Authors.

According to current regulation, the commune of Macul corresponds to the Central Inland (CI) climate zone, which is characterized as:

> Zone of template temperatures with moderate daytime oscillation, increasing towards the Andean foothills. High cloud cover. Intense solar radiation in summer. Short winters of 4 to 5 months. Moderate rainfall, tends to snow at higher levels (>500m). Frosts from May to August. Somewhat humid in the south. Moderate winds from S and SW (INN, 2019, p. 5).

It is worth adding that the commune of Macul does not have an Atmospheric Decontamination and/or Prevention Plan in force to improve the thermal efficiency of dwellings, hence the OGUC values were applied.

LABELING APPROACH

The CEV, unlike the regulation, does consider orientations. So, the results will be presented by orientation.

Figure 7 illustrates the location of the seven buildings. Concretely, the four orientations were analyzed and buildings 2, 3, 4 and 5 were assessed.

The CEV tool was applied to the four blocks in the study, each of which has 16 apartments. So, 64 evaluations were made.

In Figure 8, the standard façade of the buildings can be seen, which is then drawn following their different orientations for a direct reading of the labels obtained in their rating.

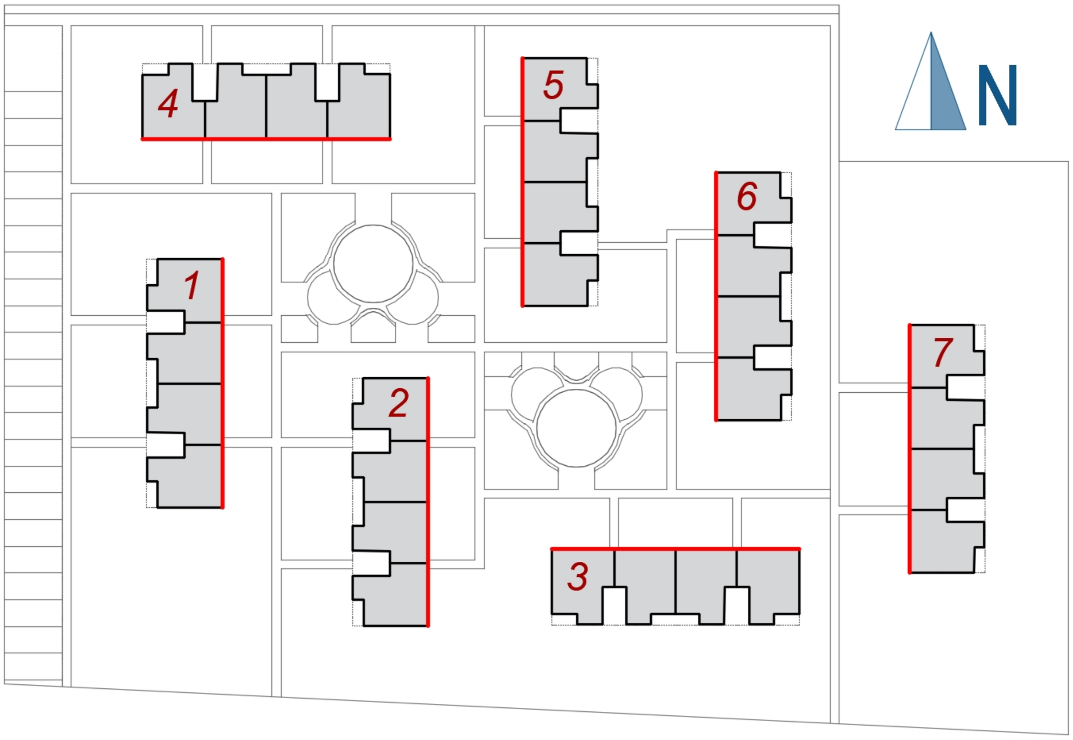
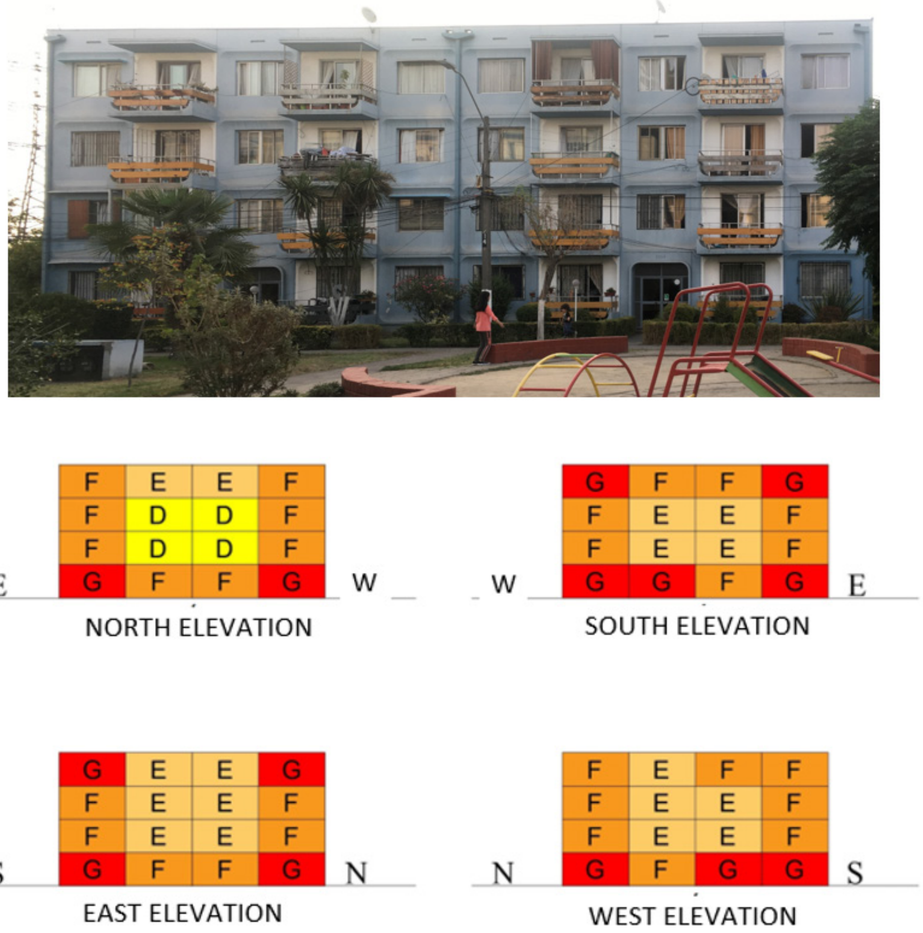


Figure 7. Orientations. Main façade outlined in red. Source: Preparation by the Authors.



F	E	E	F
F	D	D	F
F	D	D	F
G	F	F	G

NORTH ELEVATION

G	F	F	G
F	E	E	F
F	E	E	F
G	G	F	G

SOUTH ELEVATION

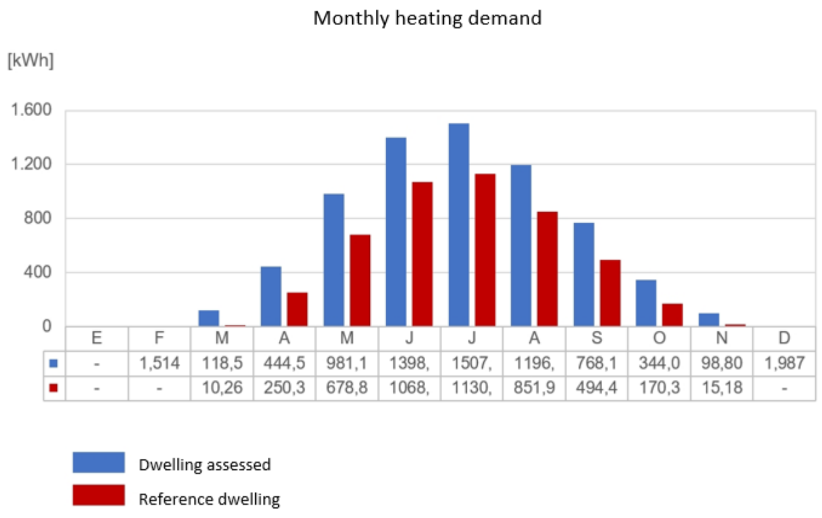
G	E	E	G
F	E	E	F
F	E	E	F
G	F	F	G

EAST ELEVATION

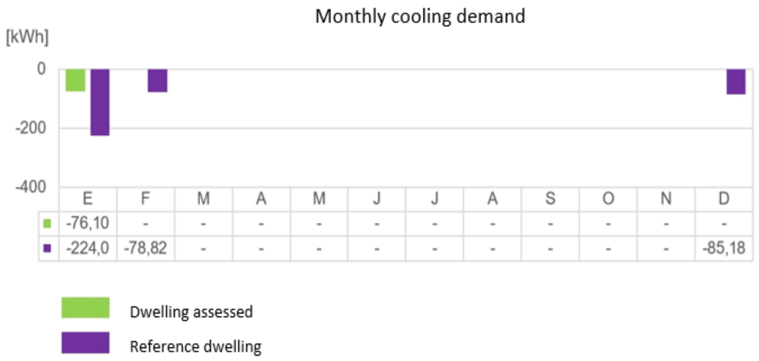
F	E	F	F
F	E	E	F
F	E	E	F
G	F	G	G

WEST ELEVATION

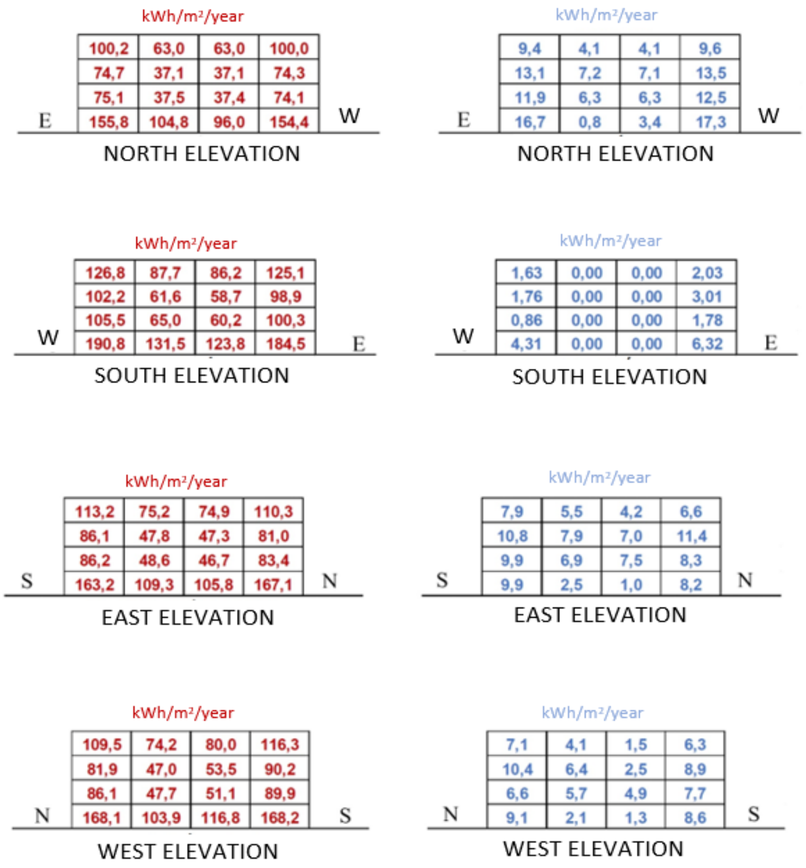
Figure 8. Ratings by orientation. Source: Preparation by the authors.



	E	F	M	A	M	J	J	A	S	O	N	D
🟦	-	1,514	118,5	444,5	981,1	1398,	1507,	1196,	768,1	344,0	98,80	1,987
🟥	-	-	10,26	250,3	678,8	1068,	1130,	851,9	494,4	170,3	15,18	-



	E	F	M	A	M	J	J	A	S	O	N	D
🟩	-76,10	-	-	-	-	-	-	-	-	-	-	-
🟪	-224,0	-78,82	-	-	-	-	-	-	-	-	-	-85,18



kWh/m²/year

100,2	63,0	63,0	100,0
74,7	37,1	37,1	74,3
75,1	37,5	37,4	74,1
155,8	104,8	96,0	154,4

NORTH ELEVATION

kWh/m²/year

9,4	4,1	4,1	9,6
13,1	7,2	7,1	13,5
11,9	6,3	6,3	12,5
16,7	0,8	3,4	17,3

NORTH ELEVATION

kWh/m²/year

126,8	87,7	86,2	125,1
102,2	61,6	58,7	98,9
105,5	65,0	60,2	100,3
190,8	131,5	123,8	184,5

SOUTH ELEVATION

kWh/m²/year

1,63	0,00	0,00	2,03
1,76	0,00	0,00	3,01
0,86	0,00	0,00	1,78
4,31	0,00	0,00	6,32

SOUTH ELEVATION

kWh/m²/year

113,2	75,2	74,9	110,3
86,1	47,8	47,3	81,0
86,2	48,6	46,7	83,4
163,2	109,3	105,8	167,1

EAST ELEVATION

kWh/m²/year

7,9	5,5	4,2	6,6
10,8	7,9	7,0	11,4
9,9	6,9	7,5	8,3
9,9	2,5	1,0	8,2

EAST ELEVATION

kWh/m²/year

109,5	74,2	80,0	116,3
81,9	47,0	53,5	90,2
86,1	47,7	51,1	89,9
168,1	103,9	116,8	168,2

WEST ELEVATION

kWh/m²/year

7,1	4,1	1,5	6,3
10,4	6,4	2,5	8,9
6,6	5,7	4,9	7,7
9,1	2,1	1,3	8,6

WEST ELEVATION

Figure 9. Monthly heating demand for one apartment Source: Preparation by the authors based on the data spreadsheet provided by CEV.
Figure 10. Monthly cooling demand for one apartment.Source: Preparation by the authors based on the data spreadsheet provided by CEV.
Figure 11. Cooling and heating demand by orientation.Source: Preparation by the authors.

Concept	Thermal sensation	Comfort vote	Spring	Summer	Fall	Winter
Unsatisfactory	Very Cold	-3				X
	Cold	-2				
Satisfactory	Somewhat cold	-1	X		X	
	Neutral	0				
	Somewhat hot	+1				
Unsatisfactory	Hot	+2				
	Very hot	+3		X		

Table 2. Example of answer about thermal sensation of the apartment without heating or air-conditioning Source: Preparation by the authors.

The CEV tool assigns the dwelling with a letter based on a total demand, as seen in Figure 8 and, at the same time, provides detail for heating and cooling demands, both monthly (Figure 9 and 10) and annually (Figure 11), which correspond to the results of an apartment used illustratively.

SUBJECTIVE ANALYSIS: SURVEYS

An onsite, face-to-face survey was given to inhabitants for the subjective assessment with the objective that users were the ones who state the thermal sensation of their apartment. The survey was applied to a sample population, using a confidence level of 80% and a sampling error of 5% and $p = q = 0.5$, with which a sample of 46 units resulted, which were drawn to choose the apartments.

The survey was made to the homeowners, 65% female and 35% male, respectively.

The survey asked to give a comfort vote for each season, pointing out whether the thermal sensation in the apartment is satisfactory or unsatisfactory. This is expressed in Table 2.

The results of the subjective analysis are presented in Figure 12, where they are grouped in graphs by season.

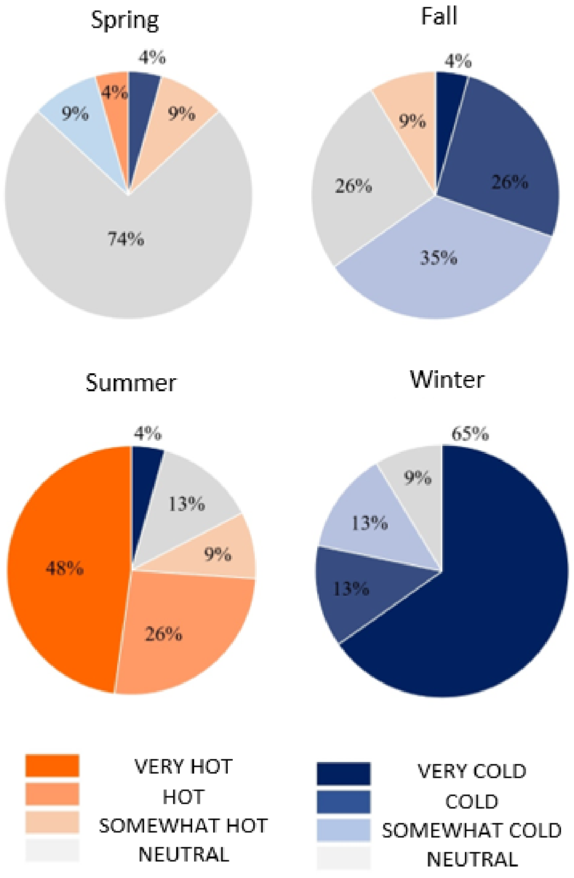


Figure 12. Comfort vote according to the dwellings' inhabitants. Source: Preparation by the authors.

ANALYSIS

As was mentioned above, the behavior of one apartment was analyzed, as an example, following the three-fold approach outlined in the diagnosis methodology used, comparing the regulations, CEV and survey, to illustrate part of the information given to us, beyond the letter.

According to CEV, the comfort range of the city of Santiago is indicated in Table 3.

The comfort temperature that the CEV considers for each thermal zone, corresponds to values determined with the method developed by Dear and Brager, adaptive model of generalized application, that determines the comfort temperature, based only on the outdoor temperature measured with a dry bulb thermometer.

	January	April	July	October
T° max.	26.6 °C	25.0 °C	23.6 °C	25.1 °C
T° min.	21.6 °C	20.0 °C	18.6 °C	20.1 °C

Table 3. Limit values of mean comfort temperature in °C. Thermal zone of Santiago. Values determined with Dear and Brager method.Source. Preparation by the authors based on the Procedures Manual. Chilean housing energy rating (MINVU, 2019, p. 239).

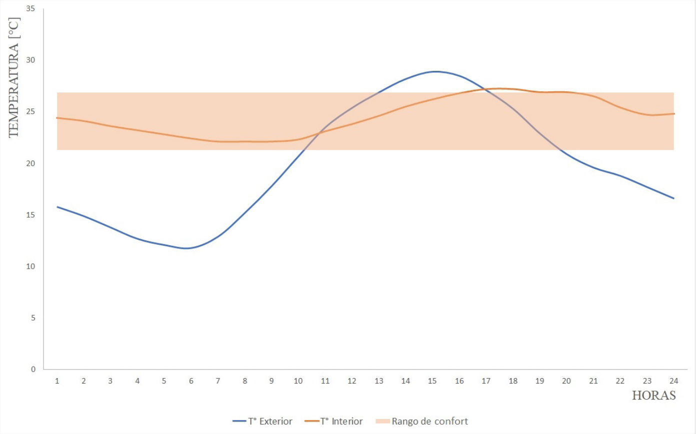


Figure 13. Representative day of January (summer). Source: Preparation by the authors based on the data spreadsheet provided by CEV.

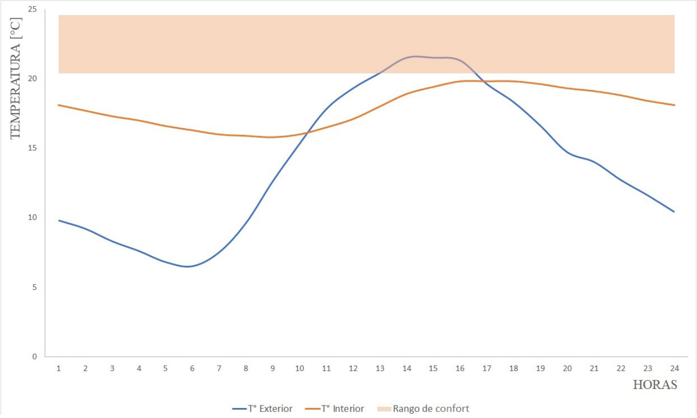


Figure 14. Representative day of April (fall). Source: Preparation by the authors

Figure 15: Representative day of July (winter).Source: Preparation by the authors.

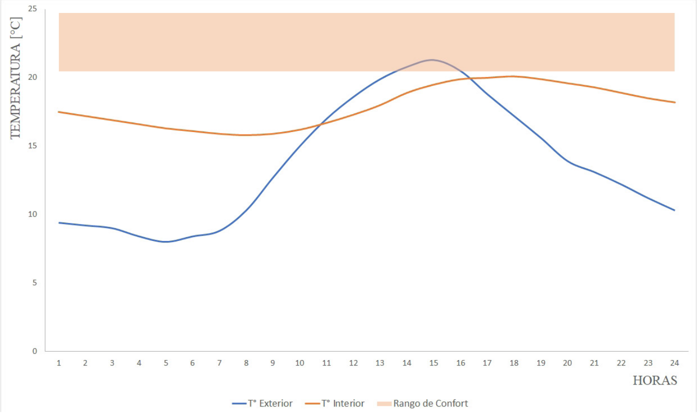


Figure 16. Representative day of October (spring). Source: Preparation by the authors.

Figures 13, 14, 15 and 16 show the temperature oscillations inside and outside one apartment, during twenty-four hours of one day, for the four seasons.

On considering this information with the survey of Table 2 (referring to the same apartment), it matches the cold sensation that is stated in winter, fall and spring. However, in January, although the temperature inside the dwelling is, according to the standard, within the comfort zone, the person surveyed states an unsatisfactory situation, as “very hot”.

CONCLUSION

After having made the thermal analysis of a building from the 1970s, the fact that all these dwellings are currently outside standards is not surprising. However, what is surprising is the resignation of their inhabitants, who manifest being uninformed or disbelief on facing the possibility of improving this situation.
The study’s three-fold approach, showed points where the regulation, energy rating and information provided

by the user agreed and did not do so. On one hand, despite that 100% of these dwellings were outside the standard, the CEV indicates that only 67% of the apartments are deficient regarding the current thermal regulation standard, i.e., they qualify as F or G.

On separating heating and cooling energy requirements, the CEV states that 100% of the dwellings in summer have a minimum cooling demand that ensures that the apartment is within comfort ranges, without needing air-conditioning systems, which is far from the perception of their inhabitants, who state in 83% of cases, that during the summer they are not in a thermal comfort state, but rather it was hot. However, for heating, a better agreement was seen. 91% of users state feeling cold, being effectively under the thermal comfort curve in all dwellings. Analyzing the orientations, the south-facing building, has a higher number of apartments in disconformity, as 3 out of 4 are rated with an F or G, but these are the ones that show a lower cooling demand within the complex, which agrees with the perception of the resident. This incoherence in the results is probably because the energy rating did not initially consider overheating in the assessment; and, although progress has been made in this sense, without a doubt there is still work to be done.

The study on existing dwellings presented here provided relevant information about the thermal comfort of the inhabitant, which finally allowed finding this discrepancy, which could be confirmed with direct measurements, in future research, looking to perfect the cooling demands that the tool determines.

It would be very useful that the CEV would separate the heating and cooling labels, so that the project could be easily evaluated by the buyer. Currently, there is a single label and, although there is an information breakdown, it is expressed through graphics, sometimes very specialized ones, that are beyond the understanding of an average buyer. This clearly goes against the spirit of the initiative, that was meant to approach consumers with a clear and attractive language.

There is no doubt that the iconic KPD apartments require energy retrofitting, which is now left subject to the organization of the community, or in other words, to the possibility of getting funds to do this and the amount for it. From this position, the survey is of great help since it is seen as a tool that is easily applicable, practical and accurate, and that involves residents in the evaluation process in first person, providing relevant information about family thermal comfort and involving people in the revaluation of their own home.

The organization, by the communities, is one of the main limiting factors the Ministry claims to provide funds, as such considering the participation of the dwelling's inhabitants, through the survey, that includes the aforementioned methodology, can contribute towards reducing the gap evidenced here to, ultimately reinforce the commitment of the neighbors with their surroundings and to revalue the territory.

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