Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

THE IMPACT OF THE COVID-19 CONFINEMENT ON THE CONCENTRATION LEVELS OF CO2 INSIDE SOCIAL HOUSING IN CHILE

Recibido 11/07/2022
Aceptado 26/12/2022

IMPACTO DEL CONFINAMIENTO POR COVID-19 EN LOS NIVELES DE CONCENTRACIÓN DE CO2 AL INTERIOR DE LA VIVIENDA DE TIPO SOCIAL EN CHILE

IMPACTO DO CONFINAMENTO POR COVID-19 NOS NÍVEIS DE CONCENTRAÇÃO DE CO2 DENTRO DE HABITAÇÕES SOCIAIS NO CHILE

Roxana Guíñez-Viveros
Magíster Hábitat Sustentable y Eficiencia Energética
Egresada Magíster Hábitat, Sustentable y Eficiencia Energética, Escuela de Ingeniería en Construcción
Facultad de Arquitectura, Construcción y Diseño, Universidad del Bío-Bío, Concepción, Chile
https://orcid.org/0000-0002-5054-0502
guinezroxana@gmail.com

Ariel Bobadilla-Moreno
Doctor en Ciencias de la Ingeniería
Director Centro de Investigación en Tecnologías de la Construcción (CITEC).
Escuela de Ingeniería en Construcción, Departamento de Ciencias de la Construcción
Universidad del Bío-Bío, Concepción, Chile
https://orcid.org/0000-0003-2781-5325
abobadil@ubiobio.cl

Cristián Alberto Muñoz-Viveros
Magíster en Hábitat Sustentable y Eficiencia Energética
Estudiante de Doctorado, Arquitecto e Investigador Centro de Investigación en Tecnologías de la Construcción (CITEC).
Departamento Diseño y Teoría, Escuela de Arquitectura, Universidad del Bío-Bío, Concepción, Chile
https://orcid.org/0000-0002-0241-7796
cmunoz@ubiobio.cl

1 Article based on the Master's thesis of the MHSEE program, "Impact of Covid-19 on CO2 concentration levels inside social housing in Chile".

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

HS

RESUMEN

Más que nunca, hasta ahora, la crisis de COVID-19 y la necesidad de permanecer más tiempo en nuestros lugares de residencia ha puesto de manifiesto la necesidad de mejorar la calidad del aire interior (IAQ) y la ventilación, con el objetivo de reducir los riesgos de transmisión de virus en el aire. A la necesidad de mejorar progresivamente el desempeño energético de nuestras edificaciones para alcanzar la carbono neutralidad, se suma esta nueva exigencia, del todo contrapuesta, que obliga a replantear la problemática de la ventilación, de sus estándares y soluciones tecnológicas para mejorar la IAQ y limitar los riesgos de contagio al interior de nuestras viviendas, sin perder de vista las metas que nos impone el cambio climático. Chile se encuentra en la búsqueda de estrategias para generar viviendas sustentables, eficientes energéticamente y confortables, que deben ser replanteadas producto del Covid-19. La mayor permanencia al interior del hogar dejó de manifiesto la precariedad en los modos de vida que enfrentan las familias más vulnerables, al exponerse en ocasiones a ambientes riesgosos para su salud. Esta investigación tuvo por objetivo estimar el impacto del Covid-19 en las concentraciones de CO2 en el aire interior, dada la intensidad de uso (ocupación) de la vivienda, considerando envolventes con distintos niveles de hermeticidad. Mediante metodología experimental, basada en simulaciones con el software DesignBuilder, se cuantificaron las concentraciones de CO2 de cuatro tipos de viviendas de carácter social, emplazadas en la comuna de Coronel, región del Biobío, Chile. Los resultados arrojaron que el confinamiento elevó en un 16,4% los niveles de CO2, mientras que el cambio de la condición original de la envolvente a niveles más herméticos generó un alza de más de un 83% en régimen de uso normal y en un 97% para periodos en confinamiento.

Palabras clave
contaminación del aire, vivienda de interés social, calidad ambiental, simulación energética.

ABSTRACT

More than ever before, the COVID-19 crisis and the need to spend longer periods of time in our places of residence, have highlighted the need to improve indoor air quality (IAQ) and ventilation to reduce the risks of airborne virus transmission. Added to the need to progressively improve the energy performance of our buildings to achieve carbon neutrality is this completely contrary new requirement, which forces reconsidering the ventilation issue, its standards, and technological solutions to improve IAQ and limit the risks of contagion inside our homes, without losing sight of the goals that climate change imposes on us. Chile is seeking strategies to generate sustainable, energy-efficient, and comfortable housing, which must be reconsidered in light of Covid-19. Greater permanence inside the home revealed the precariousness of the lifestyles the most vulnerable families face; sometimes exposing them to environments that are risky for their health. The objective of this research was to estimate the impact of Covid-19 on CO2 indoor air concentrations, as a result of the intensity of use (occupation) of the home, considering envelopes with different levels of airtightness. Using an experimental methodology, based on simulations with the DesignBuilder software, the CO2 concentrations of four types of social housing, located in the commune of Coronel, Biobío, Chile, were quantified. The results showed that confinement increased CO2 levels by 16.4%, while the change from the original condition of the envelope to more airtight levels generated an increase of more than 83% in normal use and 97% for periods of confinement.

Keywords
air pollution, social housing, environmental quality, energy simulation

RESUMO

Mais do que nunca, a crise da COVID-19 e a necessidade de permanecer mais tempo em nossos locais de residência trouxeram à tona a necessidade de melhorar a qualidade do ar interior (IAQ) e a ventilação, com o objetivo de reduzir os riscos de transmissão do vírus pelo ar. Além da necessidade de melhorar progressivamente o desempenho energético de nossos edifícios para alcançar a neutralidade de carbono, surge esta nova exigência, totalmente oposta, que nos obriga a repensar a questão da ventilação, seus padrões e soluções tecnológicas para melhorar o IAQ e limitar os riscos de contágio dentro de nossas casas, sem perder de vista os objetivos impostos pelas mudanças climáticas. O Chile está em busca de estratégias para gerar moradias sustentáveis, energeticamente eficientes e confortáveis, que devem ser repensadas em consequência do Covid-19. A maior permanência dentro do lar revelou a precariedade dos estilos de vida enfrentados pelas famílias mais vulneráveis, que às vezes estão expostas a ambientes perigosos para sua saúde. Esta pesquisa buscou calcular o impacto do Covid-19 sobre as concentrações de CO2 no ar interior, dada a intensidade de uso (ocupação) da residência, considerando envelopes com diferentes níveis de estanqueidade ao ar. Usando metodologia experimental, baseada em simulações com o software DesignBuilder, foram quantificadas as concentrações de CO2 de quatro tipos de habitação social, localizadas no município de Coronel, região do Bío-Bío, Chile. Os resultados mostraram que o confinamento aumentou os níveis de CO2 em 16,4%, enquanto a mudança da condição original do envelope para níveis mais herméticos gerou um aumento de mais de 83% no uso normal e 97% para períodos de confinamento.

Palavras-chave
poluição do ar, habitação social, qualidade ambiental, simulação energética.

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

INTRODUCTION

In Chile, areas such as Greater Concepción destine 49.4% of their energy for heating, an excessively high percentage considering the local climatology. However, this can mainly be attributed to poor residential energy quality (Technology Development Corporation, 2019), as around 66% of homes do not meet minimum thermal insulation standards (Ministry of Energy, 2020). There are also problems associated with indoor air quality: rooms with air infiltration problems and overcrowding (Bustamante, Encinas, Martínez, Brahm & Ibaceta, 2009). This causes high CO_2 levels, which, combined with inadequate ventilation systems or a complete lack thereof, increase the occupants' exposure to unhealthy environments, jeopardizing their health and decreasing their quality of life (Cortés & Ridley, 2013; Directorate General of Industry - Energy and Mines of the Community of Madrid, 2016; Huneeus et al., 2020). To face this reality, different regulatory strategies have been developed, such as the thermal requirements established in article 4.1.10 of the General Ordinance of Urbanism and Constructions (O.G.U.C) or the Atmospheric Prevention and Decontamination Plans (PPDA) in areas considered saturated. One of these measures is the implementation of higher requirements for the dwelling's thermal envelope. Covid-19, teleworking and, in general, longer hours inside the home (Energy Poverty Network, 2019) have revealed the precariousness of the ways of life, standards of living, and comfort inside Chilean homes (Guerra, 2020). This situation is further aggravated in the country's south-central area's most vulnerable families, whose social housing does not provide adequate habitability, with an unsafe intra-household environment that leads to respiratory diseases (Encinas, Truffello, Urquiza & Valdés, 2020)(Dai & Zhao, 2022) (Bi, Aganovic, Mathisen & Cao, 2022)(Lu, Niu, Zhang, Chang & Lin, 2022).

This work aims to analyze air quality inside social housing using the quantification and characterization of CO_2 concentrations. An energy simulation and modeling method are applied to four case studies in Coronel, Biobío Region, Chile, to determine and understand the impact that envelope airtightness systems generate, considering occupant numbers and the time spent inside their homes, both in normal and intensive use periods, such as those caused by Covid-19.

METHODOLOGY

The study focused on social housing in four housing complexes located in the municipality of

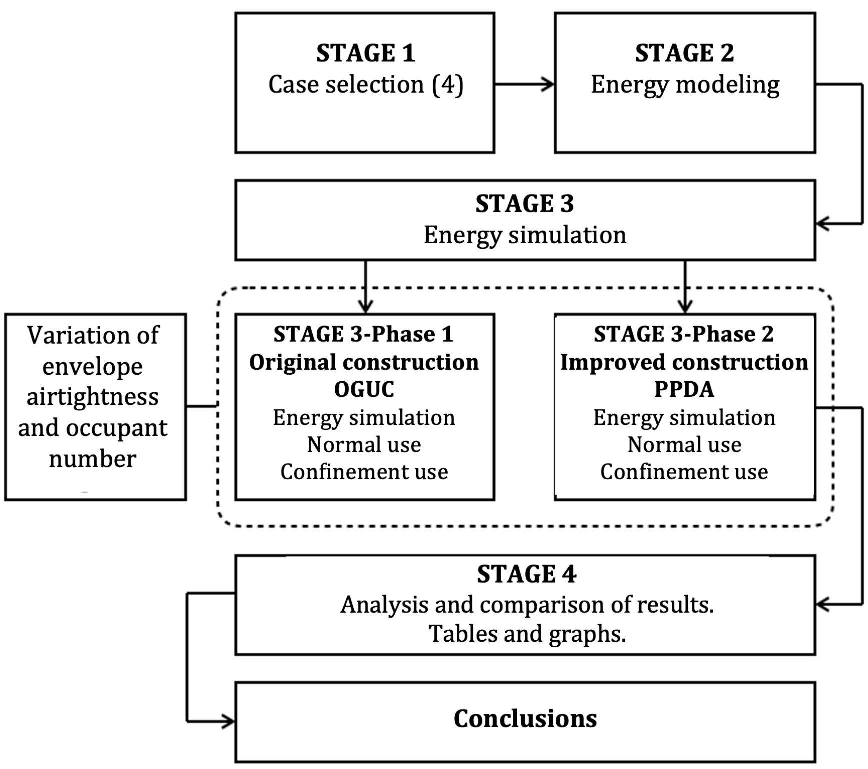

Figure 1. Sequential stages of the study. Source: Preparation by the authors.

Figure 2. Images of the main facades of the cases chosen as a sample. Source: Preparation by the authors.

Coronel, Biobío Region. It used an experimental methodology, based on energy simulations and modeling CO_2 concentration levels using the DesignBuilder software.

A non-probabilistic sample was selected, consisting of four two-level houses built using different construction systems to understand and determine how the independent envelope variables, changes in occupancy, and the number of users, affect the dependent variable, CO_2 concentration levels, and thus estimate how the incorporation of thermal insulation criteria and improvements in airtightness levels defined in the Concepción Metropolitan PPDA affect their indoor air quality. Figure 1 explains the stages of the study.

The definition of the simulation parameters, such as the boundary conditions and the air quality requirement's characterization and quantification, was based on the ventilation flow determination methodology for a dwelling's living quarters, defined in Appendix C of the Basic Document HS 3 (DB HS 3) of the Ministry of Public Works of Spain. Certain parameters and values were adapted, duly referenced to the local reality, to obtain more representative results.

CHARACTERIZATION AND QUANTIFICATION OF THE REQUIREMENTS

The indoor air quality in a dwelling will be determined by the concentration and types of pollutants that are present. One of the main pollutants inside homes is carbon dioxide (CO_2), produced by breathing and moisture. This colorless gas is usually used as an indicator of indoor air quality standards and as a parameter to evaluate ventilation performances (CITEC-UBB-Decon UC, 2014).

The characterization and quantification of the indoor air quality requirement were determined using the CO_2 concentrations defined in Appendix C of the HS 3 Basic Document, with boundary values of an annual mean of less than 900 ppm and an annual accumulated total of more than 1,600 ppm less than 500,000 ppm*h. Based on this, different cases were evaluated under the aforementioned scenarios and their results were compared with the indicator's boundary values, which would allow establishing compliance or non-compliance with acceptable indoor air quality.

Stage 1: case selection

The sample selected considered four types of social housing (Figure 2), from different housing complexes built in the municipality of Coronel between 2011 and 2019, under solidarity housing programs or funds granted directly by the Ministry of Housing and Urbanism (MINVU), or through Serviu Biobío (Biobio Regional Housing and Urbanism Service).

Table 1 provides data and details the materiality of the envelope elements of these complexes. It should be noted that those with the largest surface area in contact with the outside environment (walls) have different construction solutions, which made it possible to obtain indoor air quality data for different types of enclosures.

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

Case N°.	Materiality of the envelope			Group mode.	Sur. [m2]
	Walls	Roof	Windows		
Case 1	Reinforced concrete e=10[cm] + Polygyp plate 30[mm] attached from the inside.	Wooden structure + glass wool 11[kg/m3] e= 100[mm]	PVC, simple glazing	Semi-detached	48.5
Case 2	*1st floor: Reinforced concrete e=10 cm + EIFS system (EPS 20[kg/m3] e=60[mm]) *2nd floor: wooden structure + grooved plywood 9[mm] + insulation with EPS 20[kg/m3] e=60[mm] + EPS 30[kg/m3] e=30[mm]	Wooden structure + glass wool 12[kg/m3] e= 140[mm]	PVC, simple glazing	Detached	47.33
Case 3	Wooden structure + EPS insulation 15[kg/m3] e= 70[mm] y 40[mm]/mineral wool 40[kg/m3] e=80[mm]	Wooden structure + glass wool 11[kg/m3] e= 120[mm]	PVC, simple glazing	Detached	63.66
Case 4	*1st floor: Reinforced EXACTA® type concrete e= 18[cm] (EPS Brick 30[kg/m3] + cardboard plaster stucco 10[mm] on the inside + stucco mortar e=6[mm] on the outside *2nd floor: same solution, but brick thickness changes to 12[cm]	Vaulted Insulation type TE-130: EPS 15[kg/m3] e=100[mm]	PVC thermos-panel glazing	Semi-detached	51.75

Table 1. Data and construction characteristics of the selected cases' envelopes. Source: Preparation of the authors, based on data obtained from plans and technical specifications of each project chosen.

Stage 2: energy modeling

The simulation program is loaded with the construction information of the evaluated cases, as indicated in Table 1, and with the boundary conditions that are detailed below.

- CO_2 generation: 19 l/h per occupant, without differentiating between waking or sleeping times.
- Number of occupants: 4 occupants, based on statistical data from the Ministry of Social Development (2019).
- Occupation scenarios during normal use:
  I. Sleep periods: 8 uninterrupted hours for each occupant (between 12 and 8 am).
  II. Daytime absences: 13 hours a day for one occupant and 8 hours for the rest. Saturdays and Sundays, two absences of 2 hours per day, for each occupant.
- Occupation scenarios during the confinement period:
  I. Sleep periods: 8 uninterrupted hours for each occupant (between 12 and 8 am).
  II. Daytime absences: 13 hours a day for one occupant, the rest of the occupants perform activities from home (studies, telework). Saturdays and Sundays without absences[2].
- Exterior doors and windows of the different rooms closed
- CO_2 concentration in the outside air: an annual average of 400 ppm (CITEC-UBB- Decon UC, 2014; Ministry of Development, 2007)
- Climate data: climate file from Energyplus Weather Data, for the town of Concepción. Data associated with Coronel are adjusted: latitude, longitude, and height above sea level.
- Internal and external gains: equipment 3.9 W/m^2, lighting 7.5 W/m^2
- HVAC turned off and natural ventilation activated.

---

2 The occupation hours during confinement were based on data from surveys to measure energy poverty, associated with Fondecyt Regular project 1200551 "Energy poverty prediction based on social housing architectural design in Chile's central and central-southern zones: an innovative index to analyze and reduce the risk of energy poverty".

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

Prevailing envelope materiality	Baseline-n50 Value	Standard deviation
Concrete	9.0	5.3
Wooden framework	24.6	12.4
Other materials	10.2	4.3

Table 2. Infiltrations by construction systems. Source: Preparation by the authors. Adapted from the "Building Airtightness Manual " (Citec UBB - Decon UC, 2014, p. 32).

Cases	U [W/m²K] Walls	U [W/m²K] Roof	U [W/m²K] Ventilated floor	U [W/m²K] Windows
Adela Ester	1.26	0.43	0.67	4.87
Paso Seco I, II, and III	0.44	0.30	-	4.87
Paso Seco IV	0.37	0.36	-	4.87
Barrio Sustentable	0.61	0.41	-	2.8

Table 3. Envelope thermal transmittance value in the case studies. Source: Preparation of the authors (based on data obtained from plans and technical specifications of each project chosen).

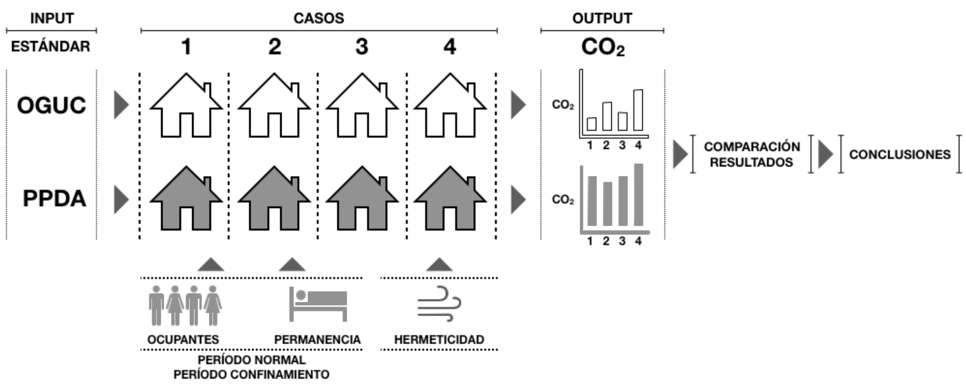

Figure 3. Summary of the procedure and main variables considered. Source: Preparation by the authors.

- Simulation period: May to September (the coldest months according to climatic data).
- Ventilation flow rates: 6 l/s-person, adapted from ANSI Addendum m (American Society of Heating Refrigerating and Air-Conditioning Engineers [ASHRAE], 2016) Standard 62.2-2013, Table 4.1b, for dwellings with surface areas between 47 and 93 m² and two bedrooms, generating the equivalent in liters per person considering 4 occupants.
- Infiltrations: those associated with each construction system (Table 2). For the PPDA improved case, this considers the envelope infiltration limit as 5 (Decree 6, 2019).
- Thermal transmittances of the envelope: as per the characteristics of the housing projects (Table 3).

Figure 3 summarizes the procedure and main variables considered in the study.

RESULTS AND DISCUSSION

STAGE 3 - PHASE 1: CO_2 CONCENTRATIONS IN THE ORIGINAL DWELLING

During the first simulation phase, the dwellings were analyzed under normal use and during confinement, considering their original constructive characteristics and the airtightness levels indicated in Table 1.

The results under normal use, shown in Figure 4, allowed verifying that the CO_2 concentrations remain under the 900-ppm limit for cases 2 and 3, while cases 1

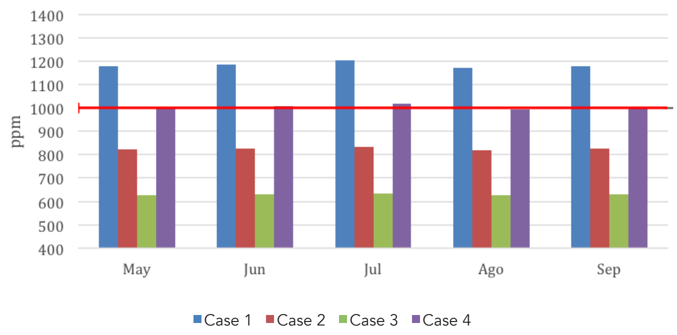

Figure 4. CO2 concentrations under normal use. Source: Preparation by the authors.

Figure 5. CO2 concentrations under con finement. Source: Preparation by the authors.

and 4 exceed these levels, reaching concentrations above 1000 ppm.

As for housing use during confinement, the results shown in Figure 5, show an increase in CO_2 levels, which exceed the 900-ppm limit in cases 1, 2, and 4. However, case 3 continues under the limit, with concentrations of 700 ppm on average.

Figure 6 illustrates the percentage increase in CO_2 levels inside the dwellings under study, generated by the change in occupancy due to confinement. Case 3 has the lowest percentage increase in CO_2 levels, while the highest is seen in Case 1.

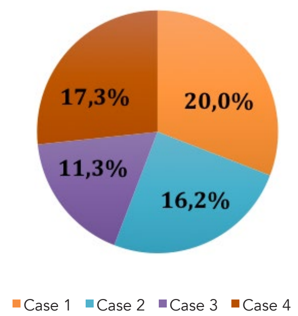

Figure 6. Percentage increase in CO2 concentrations from the change in occupancy of the dwelling. Source: Preparation by the authors.

These CO_2 concentration levels obtained are directly related to the airtightness levels assigned to the houses. For example, Case 3 is a house with a wooden construction system whose assigned airtightness baseline value (n50) is 24.6. This represents a high airflow that passes through the envelope, which evidences a poor airtightness enclosure that does not accumulate or excessively concentrate CO_2 inside the home; which is why the values obtained remain under the 900-ppm limit. On the contrary, Case 1 has the highest CO_2 concentration levels and the highest percentage increase, when moving from normal use to confinement, the result of its reinforced concrete construction system. This is the case with the lowest n50 value.

STAGE 3 - PHASE 2: CO_2 CONCENTRATIONS IN HOUSING WITH PPDA IMPROVEMENTS

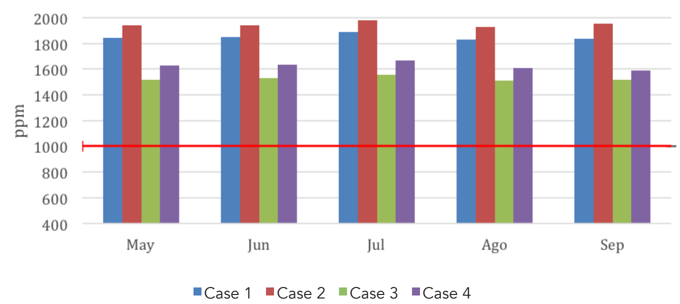

Figure 7. CO2 concentrations in normal use, incorporating PPDA criteria in the envelope. Source: Preparation by the authors.

Figure 7 plots the CO_2 concentration results obtained by the simulation in the case studies adapted to PPDA criteria: the envelopes were modified according to the thermal transmittance values required for the locality and infiltration rates were limited to 5. Under this condition, the normal occupation of the dwelling generated average CO_2 levels which fluctuated between 1500 ppm and 1900

Figure 8. CO2 concentrations in confinement, with the incorporation of PPDA criteria in the envelope. Source: Preparation by the authors.

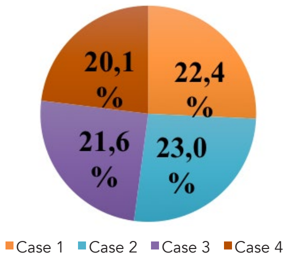

Figure 9. Percentage increase in CO2 concentrations as a result of a change in occupancy in the house, considering the adaptation of PPDA criteria. Source: Preparation by the authors.

ppm, approximately. Cases 1 and 2 showed a higher concentration of the pollutant in the indoor air.

When switching to confinement use, an increase in the cases' average CO_2 values is generated, which is between 1900 ppm and 2400 ppm, as evidenced in Figure 8, exceeding the defined limit by more than 110%.

After comparing the results obtained, it was evident that the change from normal use to confinement generated a 21.8% increase in the pollutant on average (Figure 9).

STAGE 4: DIFFERENCE OF CO_2 CONCENTRATIONS BETWEEN ORIGINAL HOUSING AND WITH PPDA IMPROVEMENTS

Through the results shown in Figures 10 and 11, the impact on CO_2 concentrations generated by the adaptation of PPDA criteria in the analyzed cases is evidenced. When evaluating these changes under normal use, the pollutant levels increased by 56.2% for Case 1 and by more than 140% for Case 3. Similarly, under confinement, Case 1 had the lowest increase, slightly exceeding 59%, while Case 3 exceeded 164% and was the case with the greatest increase in CO_2 concentration levels.

From the results, it is noted that the largest percentage differences obtained in the simulations, from adapting the envelopes of the houses under study to PPDA criteria, are mainly a consequence of the differential generated between the airtightness values of the house in the original state and the modified one, namely, the greater the differential, the greater the percentage increase in CO_2.

CO_2 CONCENTRATIONS BY USE AND INFILTRATIONS VALUE

To understand and analyze how the infiltrations affected the CO_2 levels obtained, simulations were run by modifying the airtightness levels

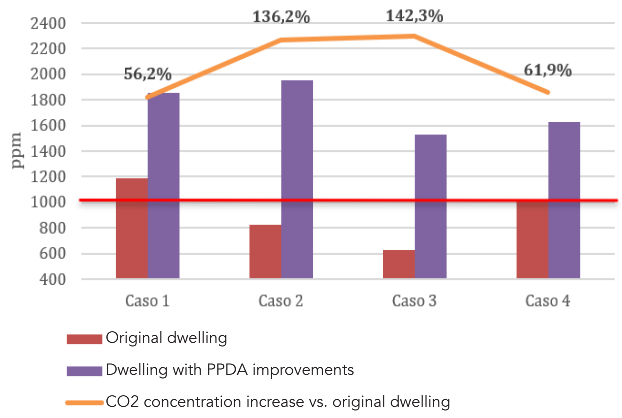

Figure 10. CO2 concentrations variations for homes with original and PPDA adapted envelope, under normal use. Source: Preparation by the authors.

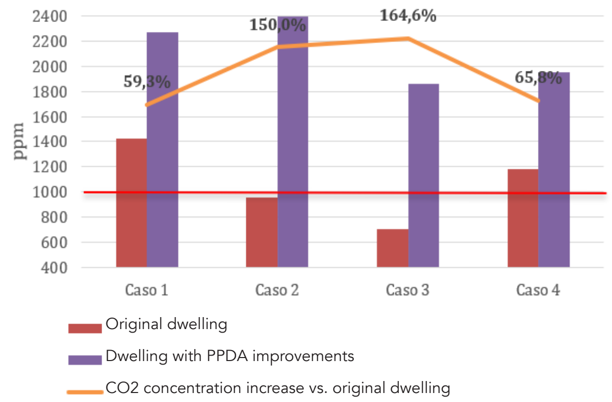

Figure 11. CO2 concentrations variations for homes with original and PPDA adapted envelope, under confinement. Source: Preparation by the authors.

between 3 and 27. The results are shown in Figure 12 and make it clear that the CO_2 concentrations, for infiltration rates between 9 and 27 renewals, tend to stay within the range of 500 - 1200 ppm, not presenting increases over 15% between consecutive airtightness values. However, towards the lower infiltration rates, namely, between 3 and 9, considerable increases occur. For example: when going from 7 to 5 air renewals per hour, the increase is approximately 30%, and from 5 to 3 infiltration rates, CO_2 levels increase by more than 50%. In addition, it is found that it is possible to maintain CO_2 levels within the average limit of 900 ppm up to 13 renewals per hour, for the four cases analyzed using the criteria defined.

In the confinement scenario (Figure 13), the results show a similar trend to the previous one, as concentrations ranging from 500 and 1200 ppm of CO_2 on average are generated for infiltration rates

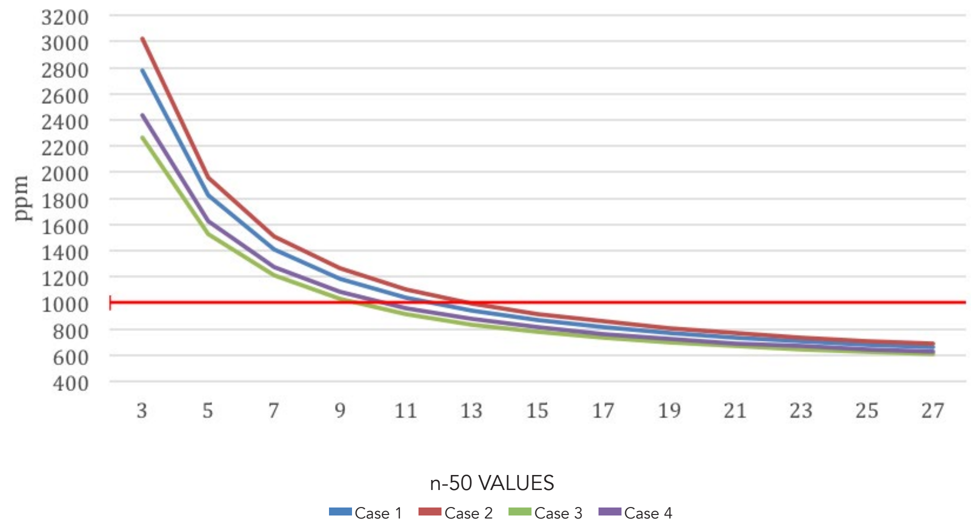

Figure 12. CO2 concentration depending on the air tightness value of the house, for normal use. Source: Preparation by the authors.

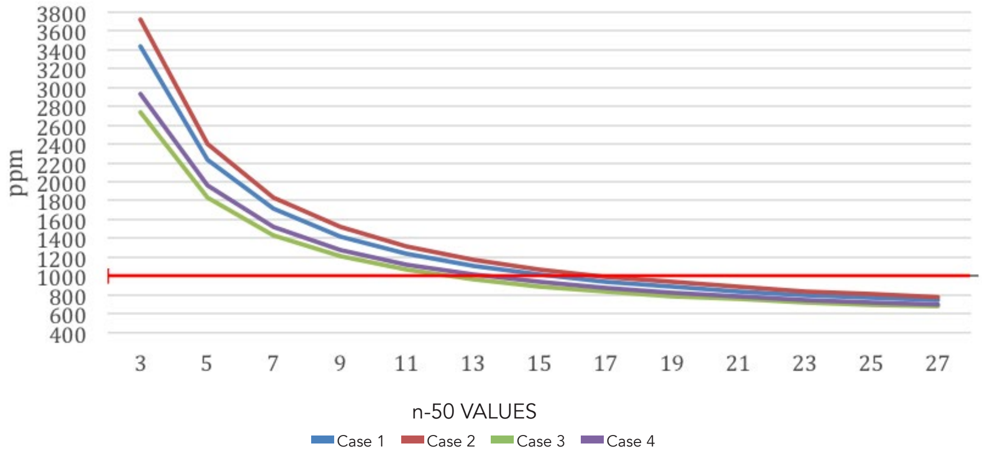

Figure 13. CO2 concentrations in ppm considering the air tightness value of the dwelling, under confinement. Source: Preparation by the authors.

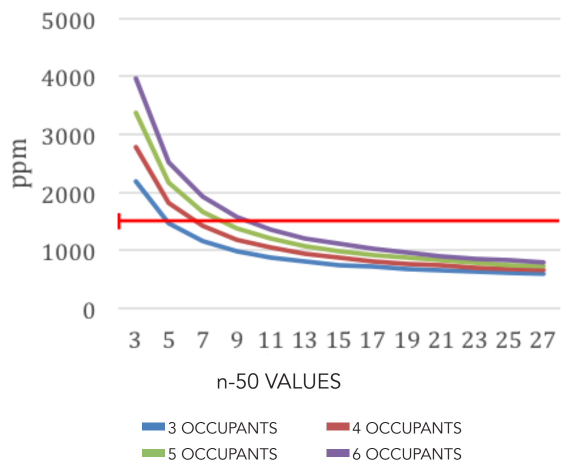

Figure 14. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 1. Source: Preparation by the authors.

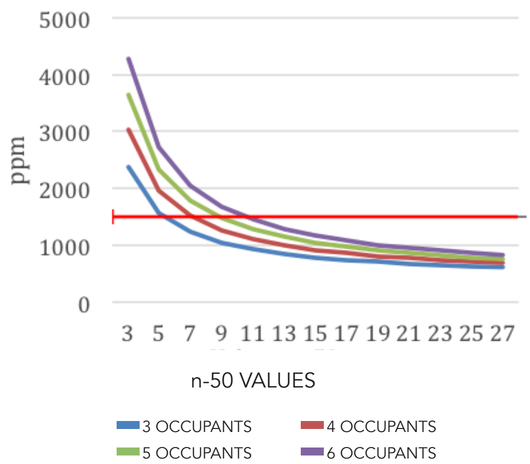

Figure 15. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 2. Source: Preparation by the authors.

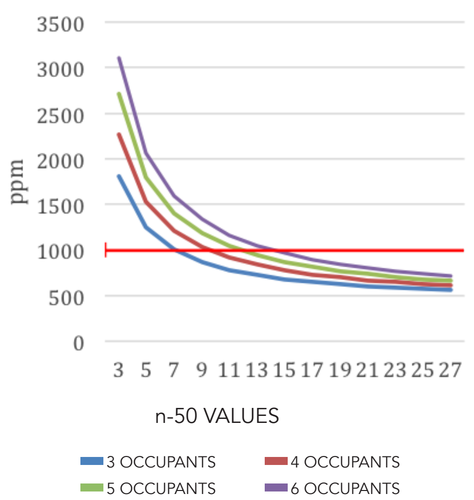

Figure 16. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 3. Source: Preparation by the authors.

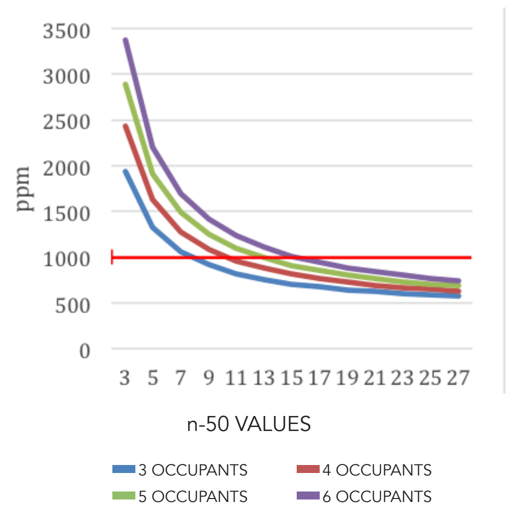

Figure 17. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 4. Source: Preparation by the authors.

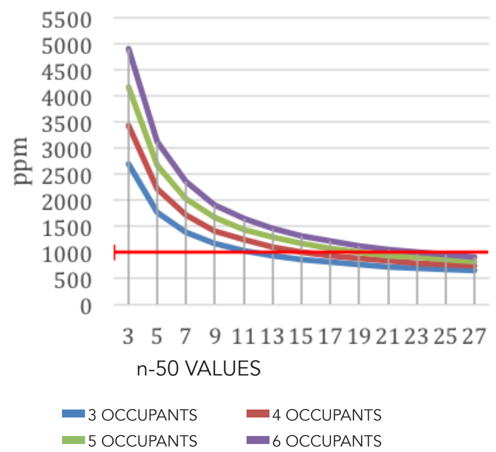

Figure 18. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 1. Source: Preparation by the authors.

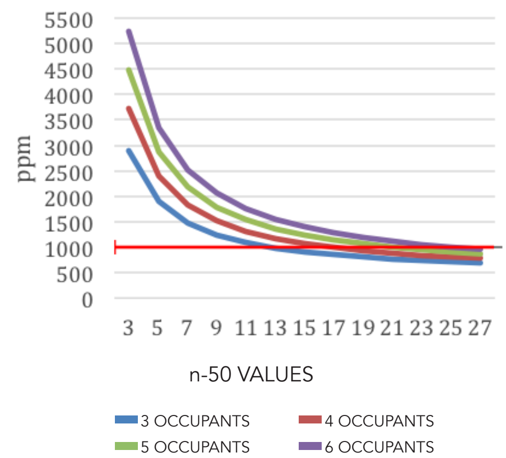

Figure 19. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 2. Source: Preparation by the authors.

between 11 and 27. With lower infiltration rates, the CO_2 levels increase by 30% when going from 7 to 5 renewals and, by more than 50% when reducing from 5 to 3 air renewals, reaching more than 3700 ppm in some of the cases studied.

CO_2 CONCENTRATIONS BY USE, NUMBER OF OCCUPANTS, AND INFILTRATION VALUE

Figure 14, figure 15, figure 16, and figure 17 show the variation results in the CO_2 concentrations for the dwellings under normal use, considering 3, 4, 5, and 6 occupants, in combination with different levels of airtightness. In the four cases studied, there is an increase in indoor air pollutant levels from the increase in the number of occupants. However, given low levels of airtightness, this increase does not tend to be proportional to the number of people added. On average, in the four cases evaluated, moving from 3 to 4 occupants with a rate of 3 air renewals per hour, CO_2 concentrations increase by 26.6%; from 4 to 5 people - by 20%, and from 5 to 6 - by 16.5%.

Figure 18, figure 19, figure 20, and figure 21 show the values obtained for CO_2 concentration levels under confinement, where the number of occupants and the airtightness levels of the cases studied vary. The results reveal that the concentration levels rise gradually between the 11 and 27 air renewals, while, when the infiltration rates decrease, the increases begin to be substantial. For example, by

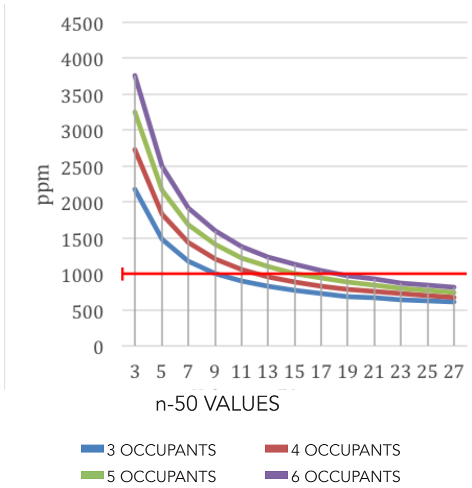

Figure 20. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 3. Source: Preparation by the authors.

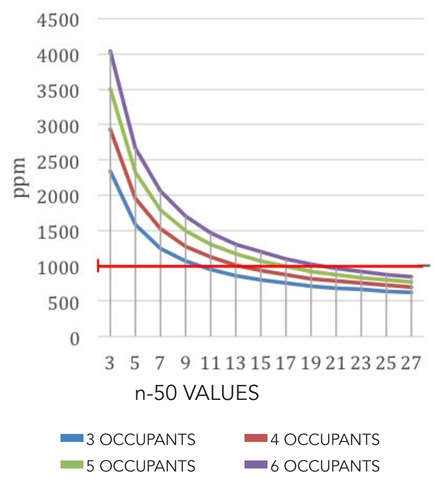

Figure 21. Variation in CO2 concentrations for the number of occupants and the level of airtightness of the house - case 4. Source: Preparation by the authors.

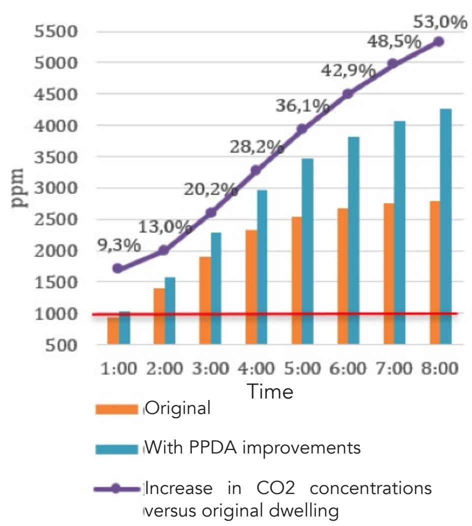

Figure 22. CO2 concentrations in bedroom case 1, with original envelope and PPDA improvements. Source: Preparation by the authors.

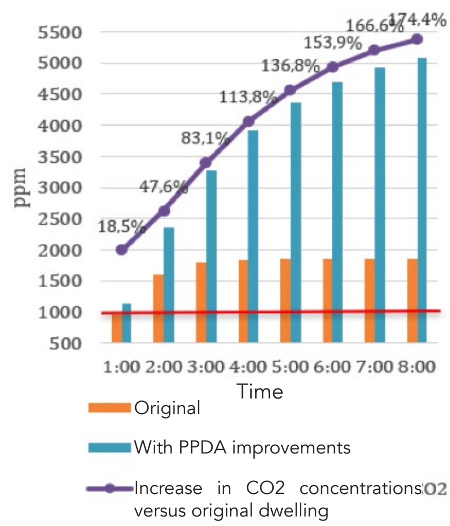

Figure 23. CO2 concentrations in bedroom case 2, with original envelope and PPDA improvements. Source: Preparation by the authors.

reducing infiltration rates from 5 to 3, concentration levels increase from 500 ppm for 3 occupants to more than 1000 ppm for the same condition, but with 6 occupants inside, they can reach 2000 ppm in Case 2. All four cases have concentrations below 900 ppm, mainly at the highest airtightness levels and with the fewest number of occupants. However, in rates under 13 renewals, the concentrations rise above the parameter, remaining outside the admissible range.

After comparing the CO_2 concentration results, it was found in the different scenarios that, by varying the number of occupants and the infiltration rates, confinement has increases ranging from 10% in pollutant levels compared to normal use, in the case of the highest airtightness levels, and close to 23%, in the case of the lowest.

CO_2 CONCENTRATIONS BY ROOMS

For the quantification and verification of the second criterion, the CO_2 levels were simulated in bedrooms, in hourly periods of use at full capacity, that is, between 12 to 8 am, with two occupants, comparing the original housing and the case with PPDA criteria under confinement. Figure 22, figure 23, figure 24, and figure 25 illustrate the CO_2 concentration levels obtained: for normal use, maxima of up to 2800 ppm were reached (cases 1 and 4) and, in the most favorable case, case 3, 1600 ppm were not exceeded. For the levels with the PPDA envelope, concentrations rose by more than 50%

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07

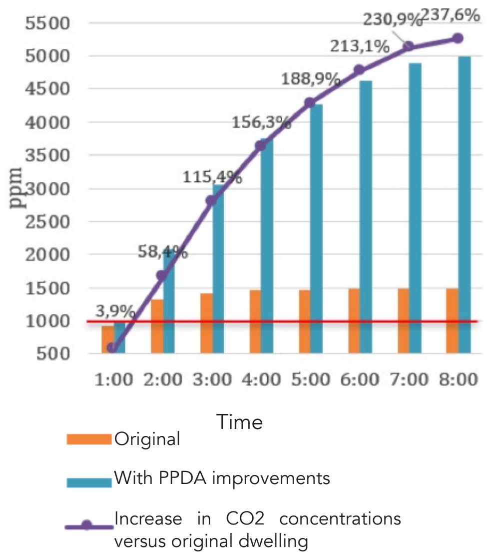

Figure 24. CO2 concentrations in bedroom case 3, with original envelope and PPDA improvements. Source: Preparation by the authors.

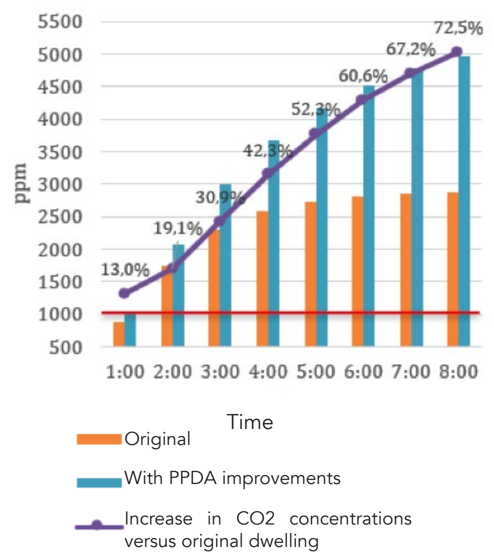

Figure 25: CO2 concentrations in bedroom Case 4, with original envelope and PPDA improvements. Source: Preparation by the authors.

for the most favorable case (case 1) and by more than 230% for the most critical (case 3). In this way, it is evident that, by limiting infiltrations through the envelope to 5, users are exposed to CO_2 levels close to 5000 ppm, during an extended period, every night, failing to comply with the annual accumulated concentrations parameter.

CONCLUSIONS

The analysis of CO_2 concentration variations inside the dwelling, as a result of modifying the envelope's characteristics and the occupancy scenarios due to Covid-19 confinement, allowed quantifying the impact that these generate on the indoor air quality in homes.

The results obtained during the first simulation phase, for CO_2 concentrations based on the original envelope, did not allow generating a representative view of the impact that airtightness and the changes of use and occupation of the dwelling have on the presence of the pollutant in the indoor air, since, although the same boundary conditions were assigned, the disparity in the infiltration rates generated results that are complex to compare; which is why scenarios were simulated by iterating airtightness levels for the case studies. This made it clear that faced with high infiltration rates, namely, between 11 and 27 air renewals per hour, the CO_2 differentials between consecutive values analyzed increase gradually. As the infiltration levels are reduced, there are increases ranging from 3% to less than 12%. For the lowest renewal rates, the increases increase almost exponentially: the most critical is the reduction from 7 to 5 air renewals, which generates an increase of more than 27% in the pollutant concentration levels, and from 5 to 3, which does so by more than 48%.

Through the results obtained, it was possible to quantify the impact that Covid-19 confinement can generate on the indoor air quality of social housing, estimating an average increase in CO_2 concentrations of about 16.4%., the result of staying longer inside the home. Likewise, the bedrooms were the rooms with the greatest exposure to unhealthy environments, because their occupants stayed longer inside them and these are the areas where the highest pollutant concentrations were generated.

Given the scope of the research and the design criteria and boundary conditions defined in the simulations, it was possible to verify that the dwelling's level of airtightness is the main variable that affects indoor CO_2 levels. This allows estimating that, if housing in Chile conforms to PPDA criteria (considering 13 as the baseline value for airtightness as defined by CITEC), the increases generated would be around 83% under the normal use scenario and 97%, in periods of confinement.

The relevance of a good design and a ventilation system that meets the real needs of Chilean families, namely, that provides sufficient ventilation flows to remove high concentrations of CO_2 that can be generated inside homes, turn out to be the key to having airtight but, at the same time, comfortable homes in all the associated habitability variables. It must be recalled that nowadays the trend is to have more efficient, airtight rooms, capable of providing adequate comfort for their occupants' different indoor activities. This brings multiple benefits at an environmental and economic level; however, it requires appropriate analysis and studies to avoid generating negative impacts at a user-health level.

The work here had an experimental approach, based on simulations under predefined conditions, which conform to normative criteria, statistical data, and information collected from the associated literature, where estimated results were obtained for each of the cases and scenarios evaluated. In future lines of research, it will be possible to use this methodology to determine ventilation requirements in homes and how the available natural ventilation capacity affects or impacts air quality, in addition to understanding how other types of indicators affect these premises, for example, indoor temperature. In the same way, it is feasible to perform fieldwork focused on *in situ* measurements of CO_2 levels in the different housing typologies analyzed in this research, where it can be verified whether the pollutant concentrations variation trends resemble those obtained by the simulation software.

BIBLIOGRAPHIC REFERENCES

American Society of Heating Refrigerating and Air-Conditioning Engineers [ASHRAE]. (2016). Ventilation and Acceptable Indoor Air Quality in Residential Buildings. *ANSI/ASHRAE Standard 62.2-2016.*, *8400*(62.2).

Bi, Y., Aganovic, A., Mathisen, H. M. y Cao, G. (2022). Experimental study on the exposure level of surgical staff to SARS-CoV-2 in operating rooms with mixing ventilation under negative pressure. *Building and Environment*, *217*. DOI: https://doi.org/10.1016/j.buildenv.2022.109091

Bustamante, W., Encinas, F., Martínez, P., Brahm, M. e Ibaceta, I. (2009). *Guía de Diseño para la Eficiencia Energética en la Vivienda Social*. Santiago de Chile: Pontificia Universidad Católica de Chile. Recuperado de: http://old.acee.cl/576/articles-61341_doc_pdf.pdf

Citec-UBB – Decon UC (2014). *Manual de hermeticidad al aire de edificaciones*. Concepción, Chile. Recuperado de: https://citecubb.cl/publicaciones.

Corporación de Desarrollo Tecnológico (2019). *Informe Final Uso de la Energía Hogares Chile 2018. Santiago de Chile*. Recuperado de: https://www.energia.gob.cl/sites/default/files/documentos/informe_final_caracterizacion_residencial_2018.pdf

Cortés, A. y Ridley, I. (2013). Efectos de la combustión a leña en la calidad del aire intradomiciliario: La ciudad de Temuco como caso de estudio. *Revista INVI*, *28*(78), 257–271. DOI: https://doi.org/10.4067/s0718-83582013000200008

Dai, H. y Zhao, B. (2022). Reducing airborne infection risk of COVID-19 by locating air cleaners at proper positions indoor: Analysis with a simple model. *Building and Environment*, *213*. DOI: https://doi.org/10.1016/j.buildenv.2022.108864

Decreto 6 de 2019. Establece Plan de Prevención y de Descontaminación Atmosférica para las comunas de Concepción Metropolitano. 25 de enero de 2018. Recuperado de: https://bcn.cl/2jf1a

Dirección General de Industria - Energía y Minas de la Comunidad de Madrid (2016). *Guía de Calidad del Aire Interior*. Madrid: Fenercom.

Encinas, F., Truffello, R., Urquiza, A. y Valdés, M. (15 mayo 2020). COVID-19, pobreza energética y contaminación: redefiniendo la vulnerabilidad en el centro-sur de Chile. *Ciper*. Recuperado de: https://www.ciperchile.cl/2020/05/15/covid-19-pobreza-energetica-y-contaminacion-redefiniendo-la-vulnerabilidad-en-el-centro-sur-de-chile/

Guerra, J. (18 julio 2020). Realizan diagnóstico que vincula calidad de la vivienda social, pandemia y cuarentenas. *Noticias UCN al día – Universidad Católica del Norte*. Recuperado de: https://www.noticias.ucn.cl/destacado/realizan-diagnostico-que-vincula-calidad-de-la-vivienda-social-pandemia-y-cuarentenas/

Huneeus, N., Urquiza A., Gayó, E., Osses, M., Arriagada, R., Valdés, M., … y Cortés, S. (2020). *El aire que respiramos: pasado, presente y futuro. Contaminación atmosférica por MP2,5 en el centro y sur de Chile*. Recuperado de: https://www.cr2.cl/contaminacion/

Lu, Y., Niu, D., Zhang, S., Chang, H. y Lin, Z. (2022). Ventilation indices for evaluation of airborne infection risk control performance of air distribution. *Building and Environment*, *222*. DOI: https://doi.org/10.1016/j.buildenv.2022.109440

Ministerio de Desarrollo Social (2019). *Informe Desarrollo Social 2019*, 14. Recuperado de: https://www.desarrollosocialyfamilia.gob.cl/storage/docs/Informe_de_Desarrollo_Social_2019.pdf

Ministerio de Energía (2020). Estrategia de transición energética de residencial. *Vivienda y Densidad*, 34. Recuperado de: https://biblioteca.digital.gob.cl/handle/123456789/3774

Ministerio de Fomento (2007). Documento Básico. *Septiembre, 2013*. Recuperado de: https://www.minrel.gob.cl/minrel_old/site/artic/20080902/asocfile/20080902204316/documento_b__sico_com__n_chile___actualizaci__n_sept_2013_final_con_correcciones_monu.pdf

Red de Pobreza Energética (2019). *Pobreza energética. El acceso desigual a energía de calidad como barrera para el desarrollo en Chile*. Policy Paper. Santiago: Universidad de Chile.

Revista Hábitat Sustentable Vol. 12, N°. 2. ISSN 0719 - 0700 / Págs. 98 - 111
https://doi.org/10.22320/07190700.2022.12.02.07