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Impact of the building airtightness and natural driving forces on the operation of an exhaust ventilation system

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The study showed a significant effect of the building airtightness and wind effect on the performance of a decentralized exhaust ventilation system in a typical social house in Chile. The supply airflow in one of the bedrooms is drastically reduced to about half of the design value, resulting in a significant increase in the CO_2-exposure for the occupants.

Keywords: Mechanical exhaust ventilation, Indoor air quality, Social housing, Airtightness, Wind pressure.

Introduction

Previous studies have demonstrated a poor thermal performance and airtightness of the envelope of social housing in Chile, resulting in surface condensation on walls, high heat losses in winter and low levels of thermal comfort for their occupants (de la Barrera et al., 2021). High levels of indoor pollutants and indoor humidity have also been observed, leading to respiratory and cardiovascular diseases in the occupants. This highlights the enormous challenge and need to retrofit social housing in Chile to achieve better standards of habitability, well-being and quality of life for its inhabitants. Current retrofitting programs for social housing primarily focus on reducing heat losses and condensation problems inside the dwellings, although they also include the installation of a decentralized mechanical exhaust ventilation system with natural air inlets in accordance with the Chilean Ventilation Standard NCh3309 (INN, 2022). However, there is currently no evaluation of the performance of such ventilation systems in the country. It is unclear whether the natural air inlets provide the required airflow rates to the different living areas of the dwelling and how the airflow rates are affected by the airtightness level of the building envelope and the natural external driving forces (wind and thermal buoyancy). This study aims to evaluate the performances of a commonly used mechanical exhaust ventilation system in a typical social housing in Chile through simulation. Specifically, the effects of the airtightness level of the building envelope and the natural driving forces on the indoor air quality are assessed using the airflow and contaminant transport calculation software CONTAM, considering the outdoor climate data of Santiago, the capital city.

Description of the case-study

The social house under investigation is an existing one-story detached dwelling with a total floor area of 43m², which is typical for a Chilean social house. It comprises a living-dining room with an open kitchen, two bedrooms and a bathroom, as shown in **Figure 1**. Bedroom 1 is assumed to face north.

A decentralized mechanical exhaust ventilation system with constant airflow in permanent regime (24 hours a day) is assumed. Each bedroom and the living room are fitted with supply vents (also known as 'inlet vents' or 'trickle vents') sized to provide 25 m^3/h per person (category II in EN16798-1) (CEN, 2019) at 10Pa, considering two adults in the master bedroom (bedroom 1), two children in the second bedroom (bedroom 2) and three people in the living room. The air is exhausted in the bathroom and in the kitchen with a total airflow equal to the total airflow supplied by the vents, in order to have a balanced ventilation system. As a result, the supplied airflow rates are: 50 m^3/h for bedroom 1, 50 m^3/h for bedroom 2, 76 m^3/h for the living room; the exhaust airflow rates are: 50 m^3/h in the bathroom and 126 m^3/h in the kitchen. **Figure 1** shows the location of the supply vents and decentralized exhaust fans.

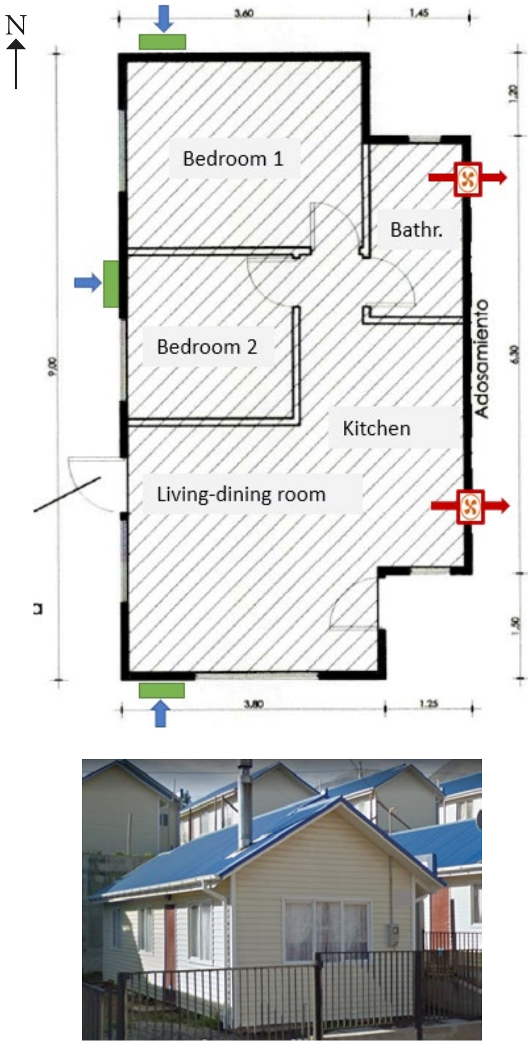

Figure 1. Plan and picture of the house investigated in this study.

The simulations in this study used the multizone indoor air quality and ventilation analysis program CONTAM to evaluate the airflows, contaminant concentrations, and occupant exposure in the building under investigation. Due to the lack of a detailed analysis of air leakage distribution in Chilean houses, it was assumed that air leakage is uniformly distributed over all vertical walls exposed to the ambient environment. Three levels of envelope airtightness were considered, expressed as air exchange rate at 50Pa (n_{50}-values): 10 h^{-1} which corresponds to the mean value for recently built houses in Chile, 5h^{-1}, which is the current requirement applied in some cities where *Air Quality Management Plans* are in force, and 0h^{-1} as an ideal case. Two scenarios for interior doors were simulated: fully open on one hand and fully closed with an undercut of 1cm on the other hand. The wind pressure on each building surface was calculated using wind pressure coefficients from the Swami and Chandra model (Florida Solar Energy Center, 1987) and a wind speed modifier coefficient to account for 'suburban' terrain. A constant indoor air temperature of 20°C was assumed.

The house was supposed to be permanently occupied by a family of four: two 40-year-old adults, and two children aged 5 and 10. Due to the lack of national data, a daily occupancy profile was created to specify the location and activity of each household member in the dwelling at each timestep.

The performance of the exhaust ventilation system was evaluated for the climate of the city of Santiago located in the central zone of Chile (~33°S) using the IWEC dataset. Santiago has a Mediterranean climate. The wind speed in the IWEC data file was modified to better match the data provided by the *General Directorate of Civil Aeronautics* for the period 2018-2022. The average wind speed is about 2.2 m/s during the heating period considered in this study (May 1 to September 30), with prevailing winds coming from the South and South-East directions.

Airflow rates

Figure 2 illustrates the calculated average outdoor (fresh) airflow rates (AR) for the living room, the master bedroom ('bedroom 1'), and the children's bedroom ('bedroom 2') over the heating period. The average ARs are very close to the design values for a perfectly airtight house (n_{50}=0 h^{-1}) when all interior doors are open: 49 m^3/h for both bedrooms and 77 m^3/h for the living room. The instantaneous AR (15-minute timestep) over the entire heating period fluctuates around the average values due to the effects of natural driving forces, mainly the wind forces, as shown in **Figure 3**. The effect of air infiltration (n_{50}=5 and 10 h^{-1}) through the building envelope is different depending on the room (**Figure 4**). The living room is more affected by air infiltration than the bedrooms due to its higher heat loss area. Additionally, the wind primarily coming from the south and southeast generates an overpressure on the facades of the living room. These two factors contribute to the increase in the total fresh airflow (ventilation + infiltration) in the living room with respect to the n_{50}-value. In contrast, the air infiltration for bedroom 2 represents a smaller fraction of the total fresh air (infiltration + ventilation), and this room is mostly exposed to under pressure due to the wind effects. As a result, the total outdoor air supply is significantly reduced compared to the design value: from 50 m³/h to 28 m³/h on average, when n_{50}=10 h^{-1}. A higher variation in the instantaneous AR is observed for a leaky building than for an airtight one (**Figure 4** versus **Figure 3**).

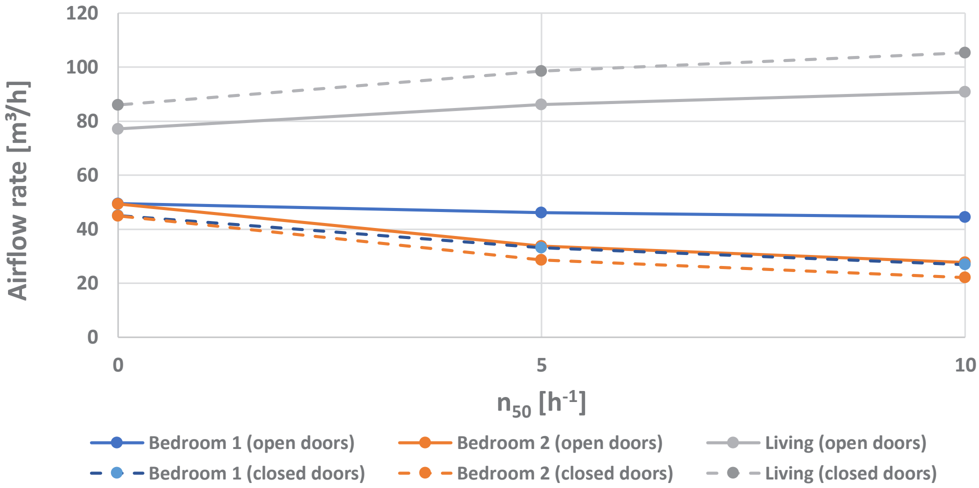

Figure 2. Average airflow rates in the living room and bedrooms over the heating period. Solid lines indicate the case with open interior doors and dotted lines the case with closed doors.

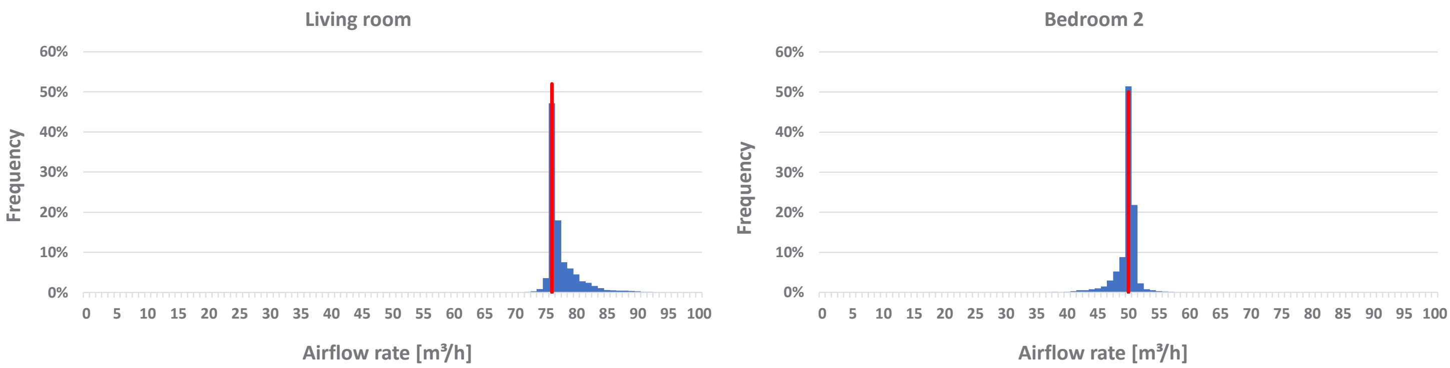

Figure 3. Frequency distribution of the outdoor airflow rates in the living room (left) and bedroom 2 (right). Perfectly airtight house, open interior doors. Vertical red line indicates the design airflow rate.

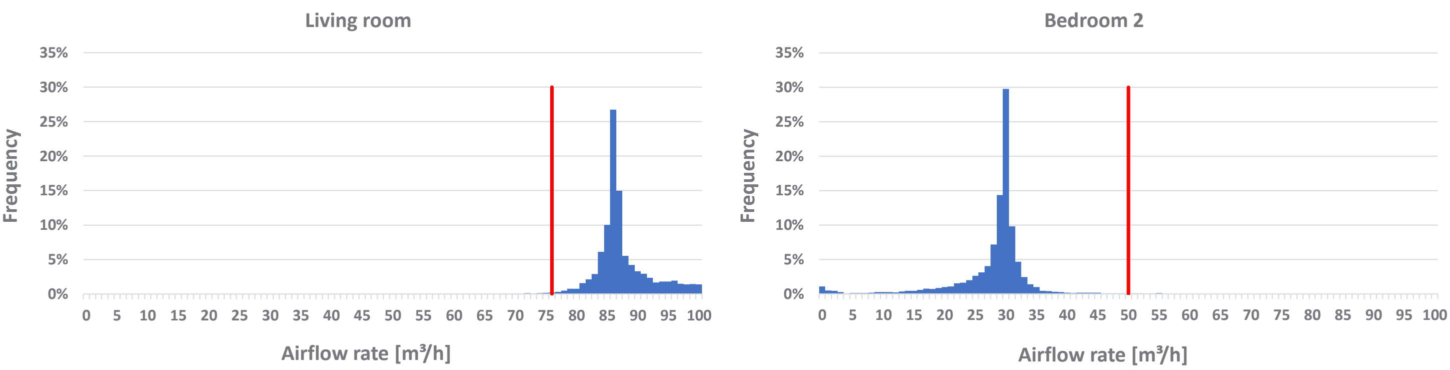

Figure 4. Frequency distribution of the outdoor airflow rates in the living room (left) and bedroom 2 (right). Leaky house (n_{50}=10 h^{-1}), open interior doors. Vertical red line indicates the design airflow rate.

When all the interior doors are closed, the aforementioned effects are further accentuated. In the house under analysis, the interior doors of the two bedrooms create an additional air resistance compared to the living room, which facilitates the supply of air through the openings of the living room (supply vent and cracks), to the detriment of the bedrooms. The average AR for bedroom 2 is only 22 m^3/h at n_{50}=10 h^{-1}, which is less than half of the nominal airflow.

CO_2-based indicators

The cumulative exceeding exposure to CO_2 above 1000 ppm during the entire heating period is given in **Figure 5** for the father and child1, assuming an outdoor concentration of 400 ppm. We also plotted the percentage of time spent in the four CO_2 concentration classes specified in EN16798-1 for the three levels of airtightness, with the interior doors open and closed (**Figure 6**).

The reduction of the supplied airflows in both bedrooms for a leaky house leads to a significant increase in the CO_2-exposure for both the father and child1. The highest exposure values are observed in the least airtight house (n_{50}=10 h^{-1}) with closed doors, which is consistent with the trends found for the airflows. In this case, the father and the child spent only 45% and 35% of their time, respectively, in an indoor space with a CO_2 concentration lower than 950 ppm, while the ventilation system was in continuous operation (24 hours a day). On the other hand,

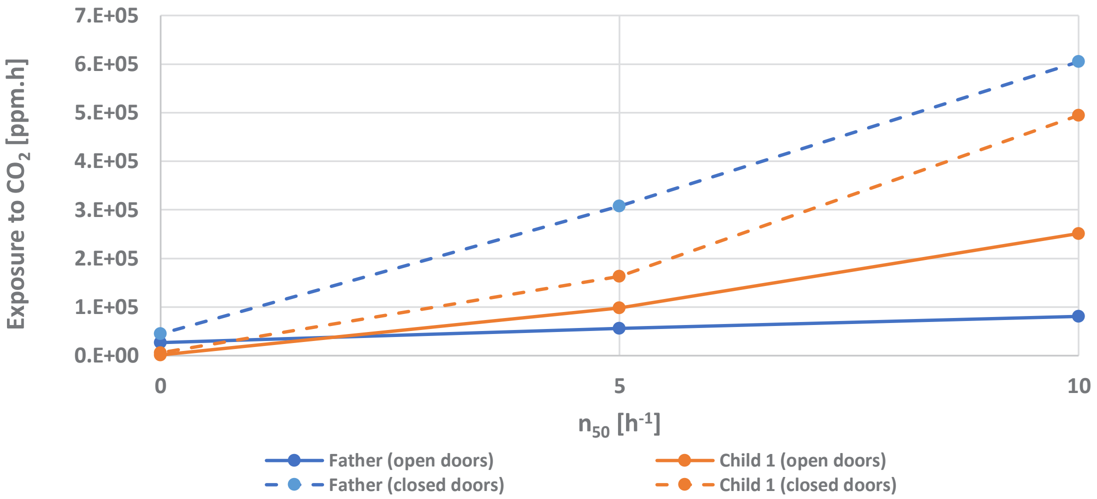

Figure 5. Cumulative exceeding exposure to CO_2 for the father and child1.

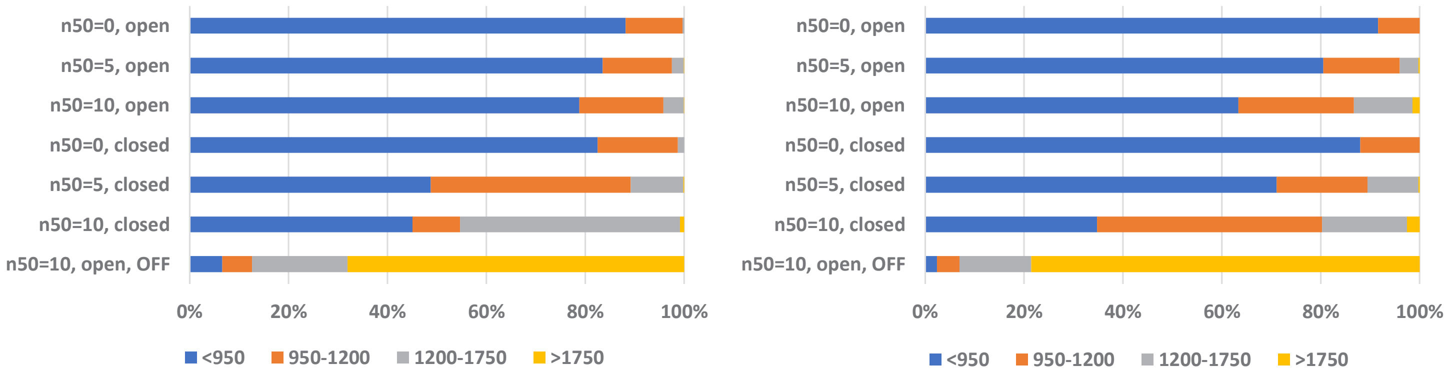

Figure 6. Percentage of time spent in four CO_2 concentration (ppm) classes for the father (left) and child1 (right).

a very good airtightness (n_{50}=0h^{-1} in our study) makes it possible to provide the design values of the airflows most of the time and, consequently, to maintain the CO_2 concentration below 950 ppm for 92% of the time for child1 when the doors are open and 88% when they are closed. As a basis for comparison, the case of a poorly airtight house (n_{50}=10 h^{-1}) with open doors was also considered, but this time without any exhaust ventilation system (bottom bar in the figure). In this case, the indoor air quality is not guaranteed at all, as the occupant is exposed to CO_2 concentrations above 1750 ppm most of the time.

Conclusions

This study has shown the significant effect of the building airtightness and the natural driving forces, mainly the wind effect, on the performance of a decentralized mechanical exhaust ventilation system with a constant airflow rate in a typical social house in Chile. For the house investigated in this research and considering a n_{50}-value of 10 h^{-1}, the supplied airflow in the living room is increased by 17% on average compared to a perfectly airtight house, while in one of the bedrooms it is drastically reduced to almost half of the value. When all interior doors in the house are closed, this effect is even more pronounced. The decrease in the supplied airflows in the bedrooms leads to a significant increase in the CO_2-exposure for the occupants. In the worst-case scenario analysed – n_{50} of 10 h^{-1} with closed interior doors – the child in the family spent only 35% of his time in an indoor environment with a CO_2 concentration below 950 ppm. These results highlight the need to work also on improving the airtightness of social houses in Chile to ensure the proper operation of installed exhaust ventilation systems.

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References

CEN. (2019). *EN 16798-1:2019, Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*.

de la Barrera, F., Rivera, M. I., Barraza, C., Durán, C., & Pavez, J. (2021). La Temperatura Importa: Confortabilidad De La Vivienda Social En San Pedro De La Costa 1. *Síntesis de Investigación*. https://doi.org/10.7764/cedeus.si.13.

Florida Solar Energy Center. (1987). Procedure for Calculating Natural Ventilation Airflow Rates in Buildings.

INN. (2022). *NCh3309, Ventilación - Calidad de aire interior aceptable en edificios residenciales - Requesitos*.

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