POLLUTANT EXPOSURE OF THE OCCUPANTS OF DWELLINGS THAT COMPLIES WITH THE SPANISH INDOOR AIR QUALITY REGULATIONS

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ABSTRACT

The Spanish Technical Building Code establishes the criteria for indoor air quality fixing minimum and constant ventilation rates per local. Currently, there is a proposal to modify the regulations so that the IAQ criteria becomes more useful by setting it based on average concentrations of CO_2 and accumulated CO_2 in the habitable rooms. However, the indoor average concentration is not the average concentration at which the occupants are exposed. This paper analyses CO_2 concentrations, occupant exposures and occupants location inside dwellings according to the Spanish Technical Building Code change proposal.
Legislation must continue advancing and adapting increasingly to the real needs of people and their protection.

KEYWORDS

Indoor air quality, regulations, CO2, occupant exposure, occupant schedule

1 INTRODUCTION

In Spain, indoor air quality (IAQ) in dwellings is regulated in the DB HS3 of the Technical Building Code (CTE) (Ministry of Development, 2006), which was enforced in 2006. Since then, research has been developed to improve this regulation in order to make it more performance-based. As a consequence of this research a proposal for a modification of the Spanish regulations establishes two possibilities:

- the compliance with CO_2 concentration ratios: the yearly average of CO_2 must be lower than 900ppm and the yearly accumulate over 1600 ppm must be less than 500 000 ppm/h; and
- the establishment of the constant flows of Table 1, as a simplified option.

Table 1: Minimum ventilation rates proposed for the Technical Building Code

Size of dwelling	**Dry rooms**			**Wet rooms**	
	Master Bedroom	Another bedrooms	Living and dining rooms	Whole minimum	Minimum per room
0 or 1 bedrooms	8	-	6	12	6
2 bedrooms	8	4	8	24	7
3 or more bedrooms	8	4	10	33	8

This paper compares the concentrations of CO_2 in the rooms and the exposure of occupants to CO_2 according to the criteria of the proposed modification of the Spanish regulation DB HS3 of the CTE.

2 CALCULATION PARAMETERS

The CO_2 generation and occupancy scenarios indicated in the proposed modification of DB HS3 were used (12l/s sleeping periods and 19 l/s rest of time).
For occupant exposures, permanent occupation and occupant schedule were considered. The efficiency of ventilation was not taken into account, assuming well mixed air.
Six recently built real dwellings were chosen to perform the analysis. These apartments are representative of the current Spanish residential building stock and can be used as dwelling types.

- Type 1: Apartment: Living/Kitchen + 2 Bedroom + 1 Bathroom
- Type 2: Apartment: Living + Kitchen+2 Bedrooms + 2 Bathrooms
- Types 3, 4 and 5: Apartment: Living + Kitchen + 3 Bedrooms + 2 Bathrooms
- Type 6: Apartment: Living + Kitchen + 4 Bedrooms + 2 Bathrooms

The case studies were classified taking into account their rooms and bathroom counts, also the number of occupants. The Spanish population and dwelling census (National Statistical Institute, 2011, 2016) was used in order to set the criteria to choose the most representative dwellings and occupancy (see some examples in Figure 1).

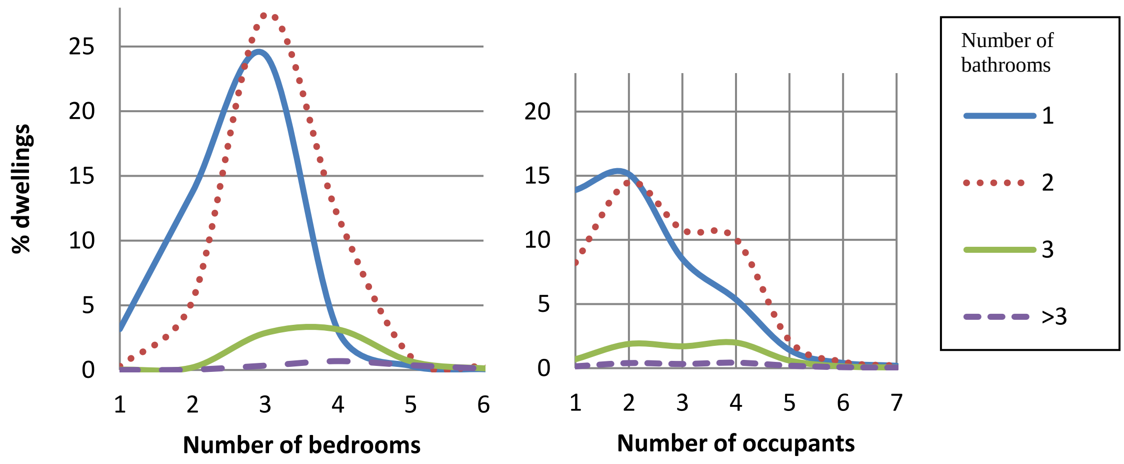

Figure 1: Number of bathrooms in Spanish dwellings according to the number of bedrooms and occupants

3 RESULTS

CO_2 concentrations in rooms, occupant exposures and their evolution over time according to the Spanish Technical Building Code change proposal have been studied. The results are described below.

3.1 Permanent occupation

When the occupants remain permanently in the dwelling in the same room, with the proposed constant ventilation flows, the steady state is reached achieving the equilibrium concentration results displayed in Table e 2. Those equilibrium concentrations are the occupant exposures.

Table 2: Occupant exposures when the occupants remain permanently in the dwelling in the same room

	Ventilation flow (l/s)	**Generation of CO_2** (l/h)	**Occupant exposures** (ppm)
Single bedroom (1 occ.)	4	12	1233
Double bedroom (2 occ.)	8	2 x 12	1233
Living room (4 occupants)	10	4 x 19	1983

At steady state, in order to not exceed an equilibrium concentration of 900 ppm CO_2 (considered as adequate air quality limit) or 1600 ppm CO_2 (considered as inadequate air quality), assuming an efficiency of 100% of the ventilation and an outdoor concentration of 400 ppm CO2, the flow rates displayed in Table 3 are needed.

Table 3: Needs of ventilation flow according with different concentrations objective

	Generation of CO2 (l/h)	**Goal equilibrium concentration (ppm)**	**Needs of ventilation flow (l/s)**
Single bedroom	12	900	6.67
		1 600	2.78
Double bedroom	2 x 12	900	13.33
		1 600	5.56
Living room (4 occupants)	4 x 19	900	31.67
		1 600	13.19

This approach is for 100% effective flow, so the actual flow rates should be higher, depending on the efficiency of the ventilation system.
However, steady state will not usually be achieved, depending -on our simplification model- of the size of the room.

3.2 Room size influence

When the occupants remain permanently in the same room, the concentration of CO_2 (constant generation) reaches the equilibrium in a time function of the room volume.

Accumulation = Generation - Elimination

$$VdC = Gdt - Q'Cdt \quad (1)$$

where:
V: volume of the room, m^3
G: pollutant generation rate, mg / h
Q ': effective ventilation flow, m^3 / h
C: concentration of the contaminant, mg / m^3
t: time, h

Considering constant volume (of the room), constant CO_2 generation (human breath) and effective constant flow rate Q, after a space of time the equilibrium will be reached: constant concentration of CO_2 in the room. The time to reach this equilibrium, in the considered case

(proposed generation, pollutant concentration, constant ventilation flow according to the proposal) will therefore depend on the volume of the rooms. Because of this, when occupants go into and out of the room before the equilibrium time, the occupant exposures are lower than the occupant exposures with permanent occupation. In addition, the occupant exposures decrease as the room size increases.
For example, in the case of a bedroom -where the occupants spend more uninterrupted time- taking useful surfaces of 5, 10 and 15 m^2 and an average height of 2.5 m, the time to reach steady state varies from 4 to 12 hours. Mean concentrations during the first 8 hours range from 1132 to 955 ppm; reaching 900 ppm at 55 ', 1h 45' and 2h 35 'respectively. Occupant exposures are showed in Table 4.

Table 4: Evolution of occupant exposures in function of bedroom size

Bedroom size (m^2)	**Ventilation flow per occupant** (l/s)	**Time to reach 900 ppm** (hour - minutes)	**Time to reach steady state** (+/- 1%, hours)	**Steady state concentration** (ppm)	**Occupant exposure after 8 hours** (ppm)	**Occupant exposure average** (ppm)
5	4	0h - 55’	4	1233	1 233	1 132
10		1h - 45’	8		1 222	1 038
15		2h - 35’	12		1 185	955

Representative Spanish single bedrooms are considered between 5 to 10 m^2, and double bedrooms between 10 to 15 m^2. Table 5 represented the results of both cases for the reason that ventilation flow is determinate according with the number of occupants.
In a real situation, in the most of the cases, occupants leave the rooms before the steady state - except small bedrooms. The occupant exposure average will be lower than the steady state concentration or the occupancy exposure of permanent occupation.

3.3 Occupant schedule

The CO_2 concentration per room and the occupant exposure for the six dwelling types are analyse using CONTAM. The used ventilation rates are the proposed for the Technical Building Code (see Table 1). Table 5 summarise it.
Occupation scenario or occupant schedule is according to the main following conditions:
- sleep periods for each occupant of 8 hours uninterrupted from 24:00 to 08:00 hours, in bedrooms;
- absences during the day:
    - from Monday to Friday an absence of 13 hours per day for 1 of the occupants and 8 hours per day for the rest;
    - Saturdays and Sundays 2 absences of 2 hours for each occupant;
- 2 occupants in the master bedroom and 1 occupant in each of the other bedrooms (until 4 occupants);
- simultaneous remain of all occupants in the living room for at least 2 continuous hours from Monday to Friday and at least 4 continuous hours on Saturdays and Sundays.

Table 5: Continuous ventilation rates values that fulfil the proposed IAQ requirements

Case study	**Total whole dwelling continuous ventilation rate** (l/s)	**Yearly average CO_2 concentration** (1) (ppm)	**Yearly CO_2 concentration accumulated over 1600 ppm** (1) (ppm·h)
1	14	834	0
2	24	772	111 754

3, 4, 5	33	930	188 804
6	33	842	178 529

(1) The highest value per room in each dwelling or the highest of the group of dwellings

For each room, the average CO_2 concentration ranges between 600 ppm and 900 ppm, with a global average of 700 ppm (see Figure 2). The red dot represents the global average. The 400ppm dot belongs to an empty bedroom in dwelling type 6 (400 ppm is the considered outdoor CO_2 concentration).

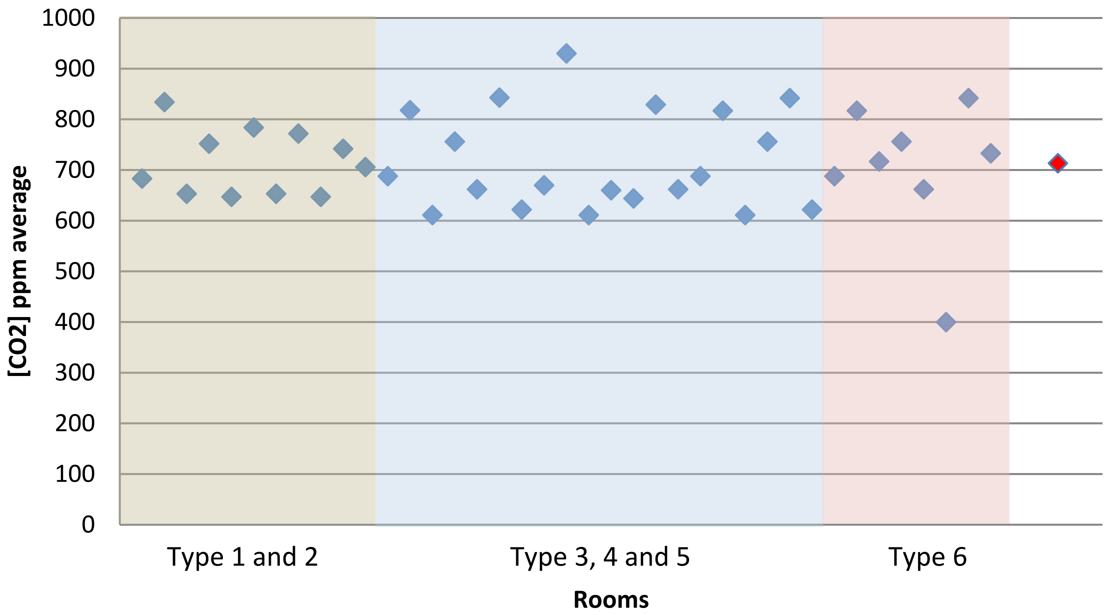

Figure 2: Average CO_2 concentration in the different rooms for the case studies. In red: global average

The average exposure to CO_2 during the period of occupation for the same case studies ranges from 969 ppm to 1238 ppm, with a global average of 1129 ppm (see Figure 3). The red dot is the global average.

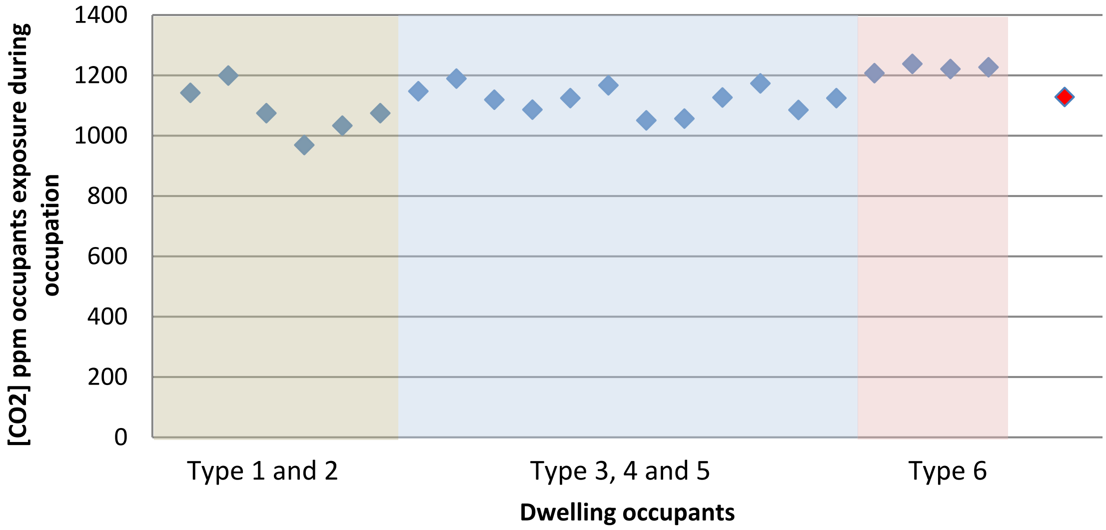

Figure 3: Occupant exposures to CO_2 in the case studies

In the case of the studied occupant' schedule and ventilation -based on constant flows-, the occupant exposures to CO_2 are higher than the average concentrations of CO_2 in rooms (see Figure 3 and Figure 4).

4 CONCLUSIONS

About the proposal Building Code change in Spain we observe that:

- in dwelling with 4 or more bedrooms the ratio $\frac{\text{total flow}}{\text{number of dry rooms}}$ decreases and the exposures increase because of the way of establishing the ventilations flows (a global minimum for wet zones);
- the general rules for establishing the occupants schedule allow the designers to modify it. Because the exposure is affected by the occupants' schedule, the occupants' protection will not be always the same.
- the exposure of occupants to CO_2 is higher than the average concentration of CO_2 in rooms. In order to protect the occupants, the regulations should focus on the occupant exposures, instead of focusing on the room average concentration.

This proposal represents a step forward because evaluates the compliance with air quality regulations according to a performance parameter such as the concentration of CO_2 in living spaces. However, the ultimate goal of the regulations is not to protect the rooms, but to protect the people.

In addition, considering an occupation higher than usual or expected could conduce to an excessive ventilation rate (more than necessary). The excessive ventilation rates increase cooling and heating demand and costs (Linares, 2015) so designers and users tend to reject them. The key would be to know how much ventilation is needed related to the real number of occupants and their schedule.

5 REFERENCES

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