Journal of Building Engineering 65 (2023) 105649

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Natural ventilation as a healthy habit during the first wave of the COVID-19 pandemic: An analysis of the frequency of window opening in Spanish homes

Miguel Ángel Navas-Martín [a], Teresa Cuerdo-Vilches [b,*]

[a] *Escuela Nacional de Sanidad (ENS), Instituto de Salud Carlos III (ISCIII), Spain*
[b] *Instituto de ciencias de la construcción Eduardo Torroja (IETcc), Consejo Superior de Investigaciones Científicas (CSIC), Spain*

ARTICLE INFO

Keywords:
Housing
Confinement
Quarantine
Habit
Health risk
Survey
Indoor air quality
IAQ
IEQ
Indoor environmental quality

ABSTRACT

Since SARS-CoV-2 spread worldwide in early 2020, many countries established lockdowns for protection. With a main transmission by aerosols, ventilation was promoted. This article analyses natural ventilation of Spanish housing during the spring 2020. An online questionnaire was launched, obtaining for this study 1502 responses. The comparative window opening before and during confinement, and households, dwellings and home activity variables, were analysed. The binary logistic regression model before pandemic indicated that ventilating properly related to: a worse perceived IAQ (OR = 1.56); thermal adaptation measures, especially those that prefer to open/close windows (OR = 1.45); not having heating system (OR = 1.15); and using power to heat water (OR = 1.60). For the confinement period, the model highlighted: being an employee (OR = 1.88); using heavy clothing in the home (OR = 2.36); and again, open/close windows for adaptation (OR = 2.24). According to specific tasks in quarantine, frequent ventilation was boosted by: an increasing use of oven (OR = 14.81); and alteration of work-habits (OR = 2.70), sport-habits (OR = 1.79), and outdoor-activities (OR = 1.60). Thus, an adequate natural ventilation pattern during the quarantine was linked to low environmental comfort in general, by virtue of indoor air quality. This is corroborated by less acoustic-thermal insulation, worse indicators of heating use, and the adaptive response to opening/closing windows when external temperature changed.

1. Introduction

On March 11, 2020, the World Health Organization communicated the situation of pandemic due to the increase in the number of cases of COVID-19 [1]. With the WHO declaration of health emergency caused by a new coronavirus, most countries carried out mobility restrictions [2]. Spain was one of the most affected countries in Europe by SARS-CoV-2 [3]. On March 14, the Spanish Government declared a State of Alarm with a series of measures to protect the health and safety of citizens [4].

Among the main non-pharmacological measures that many countries opted for, physical distancing, isolation and quarantine highlighted. Quarantine was in some countries mandatory or at least suggested as voluntary [5]. In Spain, a strict confinement was chosen, coinciding with the first wave of the pandemic. The Spaniards had to adapt to the new circumstances of confinement, altering their routines, time allocation and habits in their homes [6].

* Corresponding author. Instituto de ciencias de la construcción Eduardo Torroja (IETcc), CSIC, C/ Serrano Galvache 4, 28033, Madrid, Spain.
E-mail address: teresacuerdo@ietcc.csic.es (T. Cuerdo-Vilches).

https://doi.org/10.1016/j.jobe.2022.105649
Received 11 August 2022; Received in revised form 18 October 2022; Accepted 28 November 2022
Available online 14 December 2022
2352-7102/

Until an epidemic occurs, little information is available, and therefore it is necessary to adopt measures to improve diagnostic methods and treatment efficiency, analyse transmission patterns, and define quarantine and isolation and any other social protective strategies, mainly for infected patients [7].

One of the controversies originated between the WHO and the scientific community was the lack of consensus and approval about the routes of contagion by air [8]. In April 2021, through a guide of recommendations, the WHO suggested the ventilation control in buildings to improve indoor air quality and avoid the risk of contagion by COVID-19 [9].

In Spain, the Ministry of Health recommended during the first wave: physical distancing; avoiding hand contact with eyes, nose and mouth; hand washing; use of disposable handkerchiefs; and coughing or sneezing over the cubital fossa [10]. During the third wave, the 6M information campaign included more ventilation among the recommendations, promoting outdoor activities and window opening [11].

Natural ventilation of interior spaces is the most primitive and widespread way of eliminating all kinds of indoor pathogens of any nature, in these environments. With the introduction of outside air, that contained in the closed space is renewed, boosting the old one outdoors [12].

Depending on how the air indoors is replaced by new one, ventilation can be defined as natural (directly by opening holes to the outside, and by simple or combined action of temperature and/or pressure changes between outside and inside), mechanical (using inlet and/or outlet fans, which lead the air by ducts, previously passing through filters and other elements for its adaptation), or hybrid, as a mixture of the two previous ones, depending on the indoor and outdoor environmental conditions. The last two constitute controlled ventilation systems, and are usually integrated into the Heating, Ventilating and Air Conditioned (HVAC) system for non-residential buildings.

In Spain, the Technical Building Code (CTE) includes the basic aspects of ventilation, in its Basic Document HS3 [13]. It is mandatory to achieve air quality inside domestic spaces; not only in living spaces, but also in waste warehouses, storage rooms, garages, and parking lots. Also, the Regulation of Thermal Installations of Buildings (RITE) establishes these characteristics for non-residential buildings [14]. This current regulation had a more effective development in 2006, when indoor air quality began to be taken into account. Previously, regulations were not so demanding, and certainly not in homes. The revolution in terms of this aspect of habitability, the Indoor Air Quality (IAQ), was not until the current regulations. In it, hybrid and mechanical ventilation systems for homes were also detailed. These new requirements avoided delegating ventilation exclusively to the occupants of the spaces, but in these ventilation systems. However, Spanish homes were built almost entirely before this regulation saw the light, and therefore, they lack these systems [15].

Therefore, in almost the total of the Spanish cases, to achieve ventilation inside, it is necessary to rely on the user's criteria. Thus, the air quality depends on the frequency with which windows are opened/closed, the time that they remain open, the intensity of use inside, the gap dimensions, and the volume of indoor environment, for instance.

During the pandemic evolution, different international organizations began to establish suggestions to ensure adequate ventilation. This preventive measure against COVID-19 was spread not only for residential buildings, but focusing on natural ventilation for domestic environments [16]. The existence of poorly-ventilated residential spaces not only affected virus transmission among cohabitants. Also, contagions crossed the spatial barriers of the home, due to air drafts between dwellings and even buildings. It produced the so-called super-contagious events, especially virulent in more densely populated cities, with compact building typologies [17].

Housing and its importance and impact on the occupants' health are widely documented [18–20]. Even so, some studies carried out during the COVID-19 pandemic, delved into the importance of the habitability aspects of the home during this period. They deepened specifically during the quarantine in social distancing, and in physical health, including mental [21]. Many of them were based on reviews of existing literature to highlight the importance of indoor environmental quality. In particular, the air quality in these environments stood out [22], both for the well-being of cohabitants, and to demonstrate a lower transmission of COVID-19 in the home.

However, few studies have been able to establish in situ measurements in dwellings during this period, due to circumstances of social isolation. Although the interest and relevance of these studies should not be denied, others were able to reach the population through online questionnaires.

Among the few COVID-19 studies that addressed housing characteristics, some highlighted the concern of cohabitants and ventilation throughout the pandemic. According to a study in China, at the beginning of the outbreak, 92.4% of the sampling opened windows to ventilate more frequently than usual [23]. In another study in England, during late 2020, 58.5% of respondents opened windows frequently/very frequently in the previous 7 days [24]. At the beginning of 2021, in a multi-country study of people teleworking from home, 86.2% of respondents from UK and 94.3% from Italy declared to have opened windows to ventilate [25].

This study is the only one at the national level (and of the few internationally developed) that tried to respond to the general behaviour of the Spanish population in confinement, specifically approaching its relationship with domestic spaces and their environmental characteristics. The research questions for this analysis were established in two stages: 1) what the sociodemographic households' characteristics, and the dwelling features were, from adequately ventilated homes (in terms of frequency of window opening) before the pandemic, and 2) what aspects influenced, and/or what circumstances led those who ventilated poorly before the pandemic, to improve the frequency of opening windows during the confinement, that is, changing this habit, to reach an adequately ventilation.

2. Materials and methods

To carry out this work, a non-probabilistic cross-sectional study was carried out in households during the first wave of the pandemic in Spain. Specifically, the data collection took place between April 30 and June 22, 2020, which also coincided with the State of Alarm period decreed by the Government of Spain, in which the population was confined to their homes.

2.1. Data collection

For data collection, the SurveyMonkey® online platform was used, through a questionnaire with 58 questions grouped into 18 blocks, about participants, characteristics of their home and habits of use of domestic space.

The selection of participants was carried out through an intentional non-probabilistic sampling. Through various means of dissemination, such as the institutional website, email, social networks and the media, a call was made for their participation. Likewise, for dissemination by email, a list of contacts was created using the web scraping technique, which made possible to obtain contacts from neighbourhood associations, networks and city councils throughout the national territory. Also, participants were asked to share the link with other people for further dissemination.

The only inclusion criterion was that participants were of legal age and that the survey would be completed by a single member of the household. To do this, an informed consent was provided in the questionnaire, in addition to give information on the scope of the study.

The study was approved by the Ethics Committee from the Spanish National Research Council (CSIC, in Spanish) with favourable report number 057/2020. This organization also funded the project.

2.2. Study design

A descriptive study is presented, determining the number of responses specially for the dependent variables, such as ventilation frequencies before and during quarantine. As a cross-sectional study, the responses for "before" and "during pandemic" periods were based on a solely sampling, and facilitated through the same online questionnaire. Statistical analysis included bivariate crosses to establish significant explanatory relationships around the ventilation habits prior to the COVID-19 pandemic, as well as positive habit-changes, produced during the confinement of the first wave of coronavirus. Likewise, in order to test the multivariate explanatory relationships, three binary logistic regression models were carried out for the dependent variables. They were, respectively: first, adequate ventilation before pandemic; and second and third (based on usual poor ventilation), the event of improving ventilation to adequate, during confinement. The second analysis related general explanatory independent variables, and the third is specific on lockdown-relative activities and habits. The dependent variables were established as dichotomous dummy ones. To develop the statistical analysis, the program SPSS in its version 28 was used. The general structure of the study design is graphically described in Fig. 1.

Fig. 1 shows the ventilation habits before pandemic, and the proportion of participant homes that maintained, worsened or improved these habits. Continuous stripes in arrows show the relations analysed in this manuscript, whilst discontinuous ones were not, given the poor contribution to the general analysis (by a negligible contribution).

2.3. Selected variables

To determine this analysis on ventilation as a habit, the question on the frequency of opening/closing windows was taken as the dependent variable, compared between "before" and "during" (in reference to confinement). The possible original answers were distributed on a Likert-type scale with five categories: from "continually closed", "sometimes a week", "once a day", "several times a day", and "continually open". These original categories and their relative responses were regrouped so that there remained only two: the first three were grouped as "poor ventilation", and the last two, as "adequate ventilation".

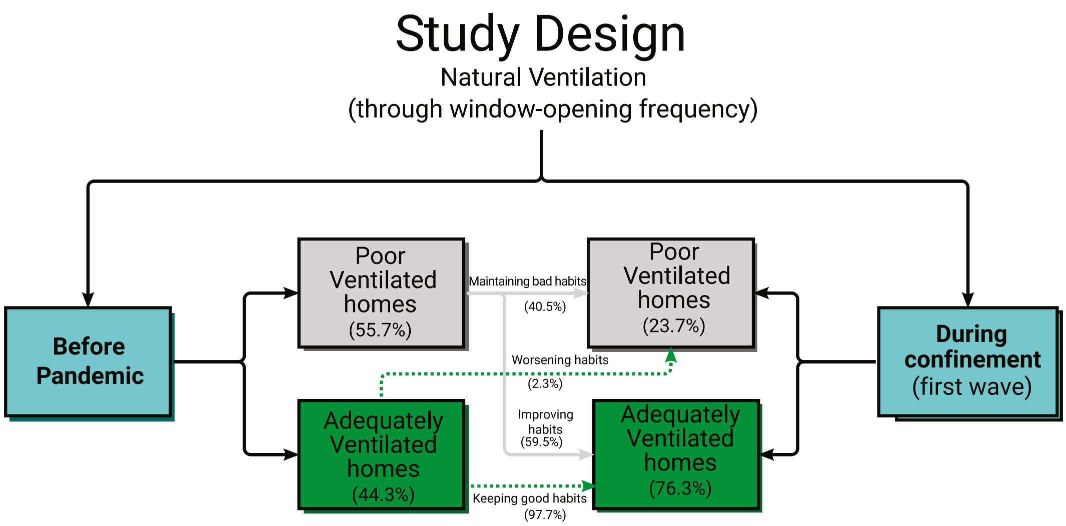

Fig. 1. Graphical description of the study design, covering a comparative natural ventilation analysis through window opening in two periods. The analysis included the relationships drawn with continuous lines, since the discontinuous ones did not seem relevant for a causal analysis, except for the mere sampling description in percentages.

The selected independent or explanatory variables, a total of twenty-eight, extracted from the 58 questions of the questionnaire, were grouped into six groups or fields to which they refer. These are listed in Table 1.

First, a selection of participants' and households' characteristics was made, such as age, gender, level of studies, job situation, cohabitants, and if minors or elders were present at home.

Second, the main home features were asked, as: housing type, tenure regime, useable floor area, availability of own external space, dwelling orientation, perceived indoor air quality, perceived lighting quality, and perceived noise insulation.

Third, questions about thermal sensation and preferences, thermal adaptation and acclimatization, were included, as well as questions about the compared energy expenditure (before and during pandemic) through housing thermal facilities, appliances and devices.

Fourth, only for the case of "during confinement", variables related to habit changes, such as "clothing change" (specially before/after going outside), "eat", "sleep", "do some physical activity", "leisure", "domestic chores", "care of someone else", etc., and also for teleworking, were asked for.

Finally, variables related to the desire of housing improvement, were added, after the reflection of being confined, and the permanent exposition to the indoor environment, also specifically for the "during confinement" period.

2.4. Data treatment and analysis

Due to the methodology followed by this study (based on the online data collection of the initial questionnaire), and its own length (with 58 questions), the questions were mostly developed with qualitative or categorical answers, to avoid abandonment of the questionnaire by participants due to tiredness or boredom.

Depending on the nature of the answers, they were structured in Likert-type scales, numeric scales, or simply in alternative answers. Those related to the alteration of habits, perceived adequacy of teleworking spaces, or in general, satisfaction with housing, allowed multiple responses, so their treatment was either by category (as an independent variable), or by regrouping the responses for later analysis (as in the case of satisfaction with the home, or the desire to improve it).

The categories are exposed in each table, according to the respective analysis. For multivariate analysis, the categories of some independent variables had to be regrouped, in order to facilitate the statistical relations among them and the dependent one, applying for each case, homogeneity criteria.

3. Results

For this study, 1502 valid responses were obtained, regarding the frequency of natural ventilation by opening windows in the home, both on a regular basis (before confinement and during it).

Once the dependent variables for ventilation frequency before and during the pandemic were prepared, the frequency distributions were observed to get a first idea of how households behaved, in terms of opening and closing windows, to facilitate natural ventilation. Fig. 1 above, exposed the relative proportions (percentages) of home ventilation, before and during pandemic. The proportions of properly ventilated housing almost did not change in the two periods, so it seemed more interesting to reflect in this study the poor-ventilated homes, and how they changed or maintained their habits, and possible reasons based in the different sociodemographic and dwelling features for "before pandemic" period (Table 2) and "during pandemic" (Table 3), when confinement-related activity changes also happened (Table 4).

Before pandemic, 55.7% of sampling ventilated poorly, and 44.3% did it properly. From those how ventilated adequately before, just 2.3% worsened this habit. But, from usual poor-ventilated homes, a 59.5% improved their habit during confinement, but the remaining 40.5% kept their bad ventilation patterns.

After observing the compared dependent variables, a decision on the bivariate analysis and the way to compare the ventilation behaviours (before and during lockdown) was made. The reason was to show, as far as possible, the most relevant behaviour changes between those two stages, and give some explanations on the potential causes that could origin them. Finally, two models were exposed, one for each stage, based on significant bivariate relations between independent variables, and dependent ones (ventilation

Table 1
Selection of independent variables for the analysis on compared residential natural ventilation frequency (before/during quarantine).

Topics or fields	Variables
Participant's and household's characteristics	Age, Gender, completed level of studies, current job situation, number of cohabitants, living with minors, living with elders (+65)
Home features	Housing type, tenure regime, useable floor area, own external space, dwelling orientation, perceived indoor air quality, perceived lighting quality, perceived noise insulation
Thermal comfort perception and habits related to use of energy at home	Habitual clothing in the home, thermal sensation indoors (comfort), thermal preference indoors, thermal adaptation measures, type of heating system, energy source of domestic hot water, Comparative use of household appliances and devices
Teleworking and spaces intended for this activity (only for "during confinement")	Type of teleworking space, qualities of the teleworking space perceived as adequate
Other activities during lockdown (only for "during lockdown")	Alteration of habits at home
Desire for home improvement (only for "during confinement")	Desire to improve aspects of the home; desire for changes in housing (grouping of aspects); Satisfaction with the home (in essential aspects, or those related to design and construction).

Table 2
Bivariate significant relations among independent variables and natural-ventilation frequency before COVID-19 pandemic.

Variable	Ventilation frequency before COVID-19 pandemic			
	Total	Poor ventilation N (%row)	Adequate ventilation N (%row)	p*
General	1502	836 (55.7)	666 (44.3)	
Participant's and household's characteristics				
Current job situation				
Enterepreneur/self-employed	231 (20.6)	120 (51.9)	**111 (48.1)**	0.029
Employee	893 (79.4)	**535 (59.9)**	358 (40.1)	
Living with elders (65+)				0.028
No	1276 (85.4)	**725 (56.8)**	551 (43.2)	
Yes	219 (14.6)	107 (48.9)	**112 (51.1)**	
Living with minors				0.019
No	957 (64.0)	511 (53.4)	**446 (46.6)**	
Yes	538 (36.0)	**321 (59.7)**	217 (40.3)	
Living with minors (6–11 years old)				0.006
No	1265 (84.6)	685 (54.2)	**580 (45.8)**	
Yes	230 (15.4)	**147 (63.9)**	83 (36.1)	
Home features				
Dwelling type				0.031
Flat	1095 (73.3)	**627 (57.3)**	468 (42.7)	
House	398 (26.7)	203 (51.0)	**195 (49.0)**	
Own external space				0.019
No	462 (30.8)	**278 (60.2)**	184 (39.8)	
Yes	1040 (69.2)	558 (53.7)	**482 (46.3)**	
Orientation: West				0.006
No	1204 (80.2)	649 (53.9)	**555 (46.1)**	
Yes	298 (19.8)	**187 (62.8)**	111 (37.2)	
Perceived Indoor Air Quality (IAQ)				0.000
Very bad/bad/regular	198 (13.3)	106 (53.5)	**92 (46.5)**	
Good	733 (49.3)	**448 (61.1)**	285 (38.9)	
Very good	556 (37.4)	276 (49.6)	**280 (50.4)**	
Perceived lighting quality				0.000
No/little adequate	94 (6.3)	51 (54.3)	**43 (45.7)**	
Adequate	506 (33.8)	**(61.1)**	285 (38.9)	
Very adequate	544 (36.4)	**276 (49.6)**	280 (50.4)	
Totally adequate	352 (23.5)	164 (46.6)	**188 (53.4)**	
Thermal comfort perception and habits related to use of energy at home				
Habitual clothing in the home				0.012
Light	393 (26.5)	206 (52.4)	**187 (47.6)**	
Normal	900 (60.7)	499 (55.4)	**401 (44.6)**	
Heavy	190 (12.8)	**124 (65.3)**	66 (34.7)	
Thermal preferences indoors				0.000
Hotter	294 (19.9)	**175 (59.7)**	118 (40.3)	
No change	958 (65.0)	**549 (53.7)**	409 (42.7)	
Cooler	222 (15.1)	106 (47.7)	**116 (52.3)**	
Thermal adaptation measures				0.000
Cloths change	866 (59.0)	**506 (58.4)**	360 (41.6)	
Open/Close windows	425 (28.9)	195 (45.9)	**230 (54.1)**	
Turn on/off heating system	178 (12.1)	**119 (66.9)**	59 (33.1)	
Heating System				0.000
None	168 (11.2)	38 (22.6)	**130 (77.4)**	
Individual (by room/dwelling)	1091 (72.6)	**643 (58.9)**	448 (41.1)	
Collective (by building, district, etc)	243 (12.1)	**155 (63.8)**	88 (36.2)	
Energy source of Domestic Hot Water				0.000
Natural gas	842 (66.6)	**522 (62.0)**	320 (38.0)	
Power	310 (24.5)	138 (44.5)	**172 (55.5)**	
Gasoil	112 (8.9)	**66 (58.9)**	46 (41.1)	

*p value for the chi-square test of the relations of among household's characteristics and home features with the window opening before COVID-19 pandemic. A $p < 0.05$ implies a significant relationship. Bolds indicate the direction of the significant relation.

frequency before and during lockdown), to explore in a deeper way and contrast those relations, by the respective multivariate logistic regressions.

3.1. Descriptive analysis: ventilation frequency before/during pandemic

In the questionnaire offered to the participating households, the compared frequency of opening windows before and during confinement, showed a disparate behaviour. As can be seen in Fig. 1, the households that responded to "before pandemic" ($n = 1502$), showed a deficient ventilation frequency in 55.7% of the cases ($n = 836$), while 44.3% ventilated properly ($n = 666$). However, when resorting to the answers obtained about the period in confinement ("during"), the households modified their behaviour in a significant

Table 3
Bivariate significant relations ventilation frequency during COVID-19 pandemic (after a usual poor ventilation), and general independent variables.

Variable	Homes with poor ventilation before COVID-19 pandemic, having during it …			
	Total	… poor ventilation N (%row)	… adequate ventilation N (%row)	p*
General	827	335 (40.5)	492 (59.5)	
Participant's and household's characteristics				
Current job situation				<0.001
Enterepreneur/self-employed	118 (18.2)	**62 (52.5)**	56 (47.5)	
Employee	530 (81.8)	190 (35.8)	**340 (64.2)**	
Living with elders (65+)				0.011
No	118 (18.2)	279 (38.8)	**440 (61.2)**	
Yes	530 (81.8)	**54 (51.9)**	50 (48.1)	
Home features				
Dwelling type				<0.001
Flat	623 (75.8)	231 (37.1)	**392 (62.9)**	
House	199 (24.2)	**101 (50.8)**	98 (49.2)	
Own external space				0.026
No	276 (33.4)	97 (35.1)	**179 (64.9)**	
Yes	551 (66.6)	**238 (43.2)**	313 (56.8)	
Orientation: West				0.013
No	640 (77.4)	**274 (42.8)**	366 (57.2)	
Yes	187 (22.6)	61 (32.6)	**126 (67.4)**	
Thermal comfort perception and habits related to use of energy at home				
Habitual clothing in the home				0.018
Light	204 (24.9)	78 (38.2)	**126 (61.8)**	
Normal	494 (60.2)	**217 (43.9)**	277 (56.1)	
Heavy	122 (14.9)	37 (30.3)	**85 (69.7)**	
Thermal preferences indoors				0.018
Hotter	174 (21.2)	**72 (41.4)**	102 (58.6)	
No change	542 (66.0)	**230 (42.4)**	312 (57.6)	
Cooler	105 (12.8)	31 (29.5)	**74 (70.5)**	
Thermal adaptation measures				<0.001
Cloths change	501 (61.7)	**210 (41.9)**	291 (58.1)	
Open/Close windows	194 (23.9)	57 (29.4)	**137 (70.6)**	
Turn on/off heating system	117 (14.4)	**61 (52.1)**	56 (47.9)	
Use frequency of Heating system in confinement				<0.001
Never/barely	225 (28.8)	69 (30.7)	**156 (69.3)**	
Only if necessary	389 (49.8)	**177 (45.5)**	212 (54.5)	
Frequently/continuously	167 (21.4)	**74 (44.3)**	93 (55.7)	

*p value for the chi-square test of the relations of among households' characteristics and home features, with the window opening during pandemic after a poor ventilation on the basis. A $p < 0.05$ implies a significant relationship. Bolds indicate the direction of the significant relation.

percentage. Indeed, 23.7% declared poor ventilation, whilst homes practising it properly increased to 76.3%.

To analyse in more detail the dynamic and changing behaviour of the homes, a further approximation was made. Observing what percentages changed their behaviour (positive or negative), and what proportion did not change their natural ventilation habits. In this sense, among those who habitually ventilated well ($n = 666$), only 2.3% ventilated worse during quarantine, while 97.7% maintained their habits. However, the greatest change occurred in those homes that habitually ventilated badly. Of them, 59.5% changed their ventilation habits towards an adequate frequency, while 40.5% maintained their poor habit.

Observing these answers, it seemed interesting to delve into what aspects led homes to ventilate well on a regular basis, and, among those who habitually ventilated poorly. In other words, what led them to change their habits towards healthier natural ventilation frequencies, and more auspicious, opening windows.

3.2. Bivariate relations with the ventilation frequency before pandemic

The results obtained for the contingency tables or bivariate crosses using the dependent variable "ventilation frequency before COVID-19 pandemic" are presented below. The results that expressed significant relationships with the explanatory and independent variables are presented in Table 2.

Chi-square tests are implemented to find significant relations between each of the independent variables and the dependent one. P-value<0.05 implies significant relation.

As shown in Table 2, the usual natural ventilation frequency variable (before pandemic) was significantly related to multiple independent variables. In the first place, with respect to the characteristics of participants and households, the variables that showed a significant relationship were the current work situation, as well as certain configurations of the household, such as the presence of people over 65, and the coexistence of minors, and within them, minors between 6 and 11 years. The current employment situation was significantly related. The worst ventilators were those with paid employment (59.9% vs. 40.1%). The self-employed/businessmen were who ventilated more frequently on a regular basis.

Regarding the configuration of the home, living with older people was related to adequate ventilation (51.1% vs 48.9%), while minors were related to poor ventilation (59.9% vs 40.3%). This same relationship also occurred specifically for the age group of minors

Table 4
Bivariate significant relations among ventilation frequency during pandemic (after a usual poor ventilation) and independent variables (activity, habits, comfort and environmental quality).

Variable		Homes with poor ventilation before COVID-19 pandemic, having during it …			
		Total	… poor ventilation N (%row)	… adequate ventilation N (%row)	p*
General		827	335 (40.5)	492 (59.5)	
Teleworking and spaces intended for this activity					
Type of teleworking space					0.004
Itinerant or occasional shared space		400 (65.0)	133 (33.3)	**267 (66.8)**	
Previously shared or exclusive space		215 (35.0)	**97 (45.1)**	118 (54.9)	
Adequate room size					0.009
No		382 (46.2)	**173 (45.3)**	209 (54.7)	
Yes		445 (53.8)	162 (36.4)	**283 (63.6)**	
Adequate surface finishing					0.014
No		504 (60.9)	**221 (43.8)**	283 (56.2)	
Yes		323 (39.1)	114 (35.3)	**209 (64.7)**	
Other activities during confinement					
Compared use of stoves					<0.001
Less use than usual		5 (0.6)	**2 (40.0)**	3 (60.0)	
Same use as usual		296 (35.8)	**150 (50.7)**	146 (49.3)	
More use than usual		525 (63.6)	182 (34.7)	**343 (65.3)**	
Compared use of oven					<0.001
Less use than usual		17 (2.1)	**11 (64.7)**	6 (35.3)	
Same use as usual		286 (35.4)	**146 (51.0)**	140 (49.0)	
More use than usual		504 (62.5)	169 (33.5)	**335 (66.5)**	
Compared use of kitchen robot					<0.001
Less use than usual		31 (5.7)	**15 (48.4)**	16 (51.6)	
Same use as usual		298 (54.7)	**145 (48.7)**	153 (51.3)	
More use than usual		216 (39.6)	70 (32.4)	**146 (67.6)**	
Alteration of habits at home					
Working	No	172 (20.8)	**83 (48.3)**	89 (51.7)	0.020
	Yes	655 (79.2)	252 (38.5)	**403 (61.5)**	
Cleaning	No	409 (49.5)	**188 (46.0)**	221 (54.0)	0.002
	Yes	418 (50.5)	147 (35.2)	**271 (64.8)**	
Domestic chores	No	385 (46.6)	**178 (46.2)**	207 (53.8)	0.002
	Yes	442 (53.4)	157 (35.5)	**285 (64.5)**	
Clothing change	No	453 (54.8)	**204 (45.0)**	249 (55.0)	0.004
	Yes	374 (45.2)	131 (35.0)	**243 (65.0)**	
Sports	No	310 (37.5)	**149 (48.1)**	161 (51.9)	<0.001
	Yes	517 (62.5)	186 (36.0)	**331 (64.0)**	
Enjoying the external space					0.013
No		534 (64.6)	**233 (43.6)**	301 (56.4)	
Yes		293 (35.4)	102 (34.8)	**191 (65.2)**	
Desire for home improvement					
Desire for insulation improvement					0.016
No		472 (57.1)	**208 (44.1)**	264 (55.9)	
Yes		355 (42.9)	127 (35.8)	**228 (64.2)**	
Changes in housing (5+)					0.003
No		126 (15.2)	**66 (52.4)**	60 (47.6)	
Yes		701 (84.8)	269 (38.4)	**432 (61.6)**	
Home satisfaction (essential features)					<0.001
No		705 (85.2)	268 (38.0)	**437 (62.0)**	
Yes		122 (14.8)	**67 (54.9)**	55 (45.1)	

*p value for the chi-square test of the relations of between activities, habits and environmental parameters with the window opening during pandemic after a poor ventilation on the basis. A $p < 0.05$ implies a significant relationship. Bolds indicate the direction of the significant relation.

between 6 and 11 years of age (63.9% vs. 36.1%).

On the characteristics of the home, significant relationships were obtained between the usual frequency of ventilation before the pandemic and the type of home, the existence of its own outdoor space, orientation to the west, and the perceived indoor air and lighting qualities. Regarding the detailed relationships, an adequate frequency of ventilation on a regular basis was related to single-family homes (49.0% vs 51.0), with having their own outdoor spaces (46.3% vs 53.7%), with not having a west orientation in the home (62.8% vs 37.2%), and with polarized perceptions of indoor air quality and lighting, being either poor/inadequate, or very good/very adequate.

In relation to the perception of thermal comfort and the habits linked to the use of domestic energy, adequate ventilation was associated with light (47.6%) and normal clothing (44.6%), with the desire to have a cooler environment in the home (52.3%), not having a heating system (77.4%), and power energy sources to heat water for domestic use (55.5%), compared to fuel sources (gasoil or natural gas).

3.3. Bivariate relations with the ventilation frequency during pandemic

Once the bivariate relationships based on the frequency of opening windows on a regular basis (before the pandemic) were established, the ventilation frequency variable during confinement was created, especially for those homes that ventilated poorly before. This variable was done in order to observe the positive habit-change carried out by the households, just in this quarantine period, and the explanatory variables that could be associated with such change. The relations are shown in Table 3 for independent variables linked to households' and housing characteristics, comfort and use of energy, and in Table 4, for activities, alteration of habits, and desire of housing improvement, all in a context of COVID-19 lockdown.

Chi-square tests were implemented to find significant relations between each of the independent variables and the dependent one. P-value<0.05 implied significant relation.

The positive change towards a better frequency of natural ventilation was associated, in terms of characteristics of participants and households, with being an employee (64.2% vs 35.8%), and with not living with people over 65 years old (61.2% vs. 38.8%).

Regarding the dwelling characteristics, the change towards a better ventilation frequency showed significant relationships with the type of dwelling relative to living in flats (62.9% vs 37.1%), to not having an outdoor space (64.9% vs 35.1%), and to be oriented to west (67.4% vs. 32.6%).

In relation to the perception of thermal comfort and habits related to the energy use, the improvement in the compared ventilation frequency was associated with cooler clothing (61.8% vs 38.2%) or warmer than usual (69.7% vs 30.3%), in a polarized way. It was also related to having a thermal preference of wanting a slightly cooler environment (70.5% vs 29.5%).

Regarding the priority adaptation measures chosen by households when feeling uncomfortable, improved ventilation was associated with using the opening/closing of windows as an adaptive activity to regulate indoor thermal comfort (70.6% vs 29.4%). Lastly, according to the frequency of use of the heating system in confinement, those who changed their habit declared using this system not at all or rarely (69.3% vs 30.7%).

Table 4 below specifies the independent explanatory variables that established a significant relationship with those who habitually ventilated badly, and during confinement changed (or not) their behaviour patterns in that regard.

Chi-square tests were implemented to find significant relations between each of the independent variables and the dependent one. P-value<0.05 implied significant relation.

Regarding the activities carried out in the domestic space, the improvement in natural ventilation habits was associated with teleworking in non-exclusive spaces, but itinerant or circumstantially shared (66.8% vs 33.3%), as well as with teleworking spaces of appropriate dimensions (63.6% vs. 36.4%), and with good surface finishing (64.7% vs. 35.3%). In addition, the increased use of stoves (65.3% vs 34.7%), oven (66.5% vs 33.5%), and food processor (67.6% vs 32.4%), was also related to an increase in the frequency of natural ventilation.

According to the alteration of habits in the home, those households that improved their ventilation habits were significantly related to having declared alterations during confinement, in relation to: working habits (61.5% vs 38.5%), cleaning the home (64.8% vs. 35.2%), doing other home chores (64.5% vs. 35.5%), clothing change (65.0% vs. 35.0%), playing sports (64.0% vs. 36.0%), and enjoying the outdoor space (65.2% vs. 34.8%).

Finally, about the desire to improve the house, the increase in opening windows was associated with the desire to improve insulation in general (64.2% vs 35.8%), with the desire for changes in the home (at least 5) (61.6% vs 38.4%), and with the lack of satisfaction in the home, in relation to non-modifiable design and construction characteristics (62.0% vs 38.0%).

3.4. Multivariate model for the dependent variable "ventilation frequency before pandemic"

The mathematical formula that expresses a probability with a logit model, allows to establish an algebraic relation among a probability and certain categorical variables, as follows:

$$p = \frac{1}{(1 + e^{-(\alpha+\beta x)})} = \frac{1}{(1 + e^{-z})}$$

Where:

p: probability for the event to occur (being the succesful event (value = 1) for the dependent variable).

α: constant of the straight line "z" (for the entire population, or sample's universe).

β: Coefficient for each of the independent explanatory variables (also for universe),

x: the value for the explanatory variable.

For the sampling, greek letters usually are changed by latin ones:

$$p = \frac{1}{(1 + e^{-(a+bx)})} = \frac{1}{(1 + e^{-z})}$$

a: constant of the straight line "z" (for the sampling).

b: Coefficient for each independent explanatory variable (also for the sampling).

Following this expression, for each multivariate model, coefficients b (b1, b2, b3, etc) are given in the subsequent tables, for each independent-variable categories. Also, correlation coefficients obtained for each model are included at the end of the respective table.

In the hypothesis established for the first model, the dummy dependent variable "frequency of window opening before the pandemic" presented the success case (1) for the category "adequate ventilation". Table 5 reflects the results of the binary logistic regression model, based on the independent variables that showed significant relationships in the previous bivariate analysis.

Table 5 shows the results of the regression for the dependent variable "frequency of window opening before the pandemic".

As for the variables related to the characteristics of the participants and the households that showed significant relationships in the bivariate relationships, they did not show multivariate relationships in the model. In relation to the dwelling characteristics, only the perceived indoor air quality showed a significant relationship, at the variable level. At the category level, only "good" air quality showed to be significant. The relation shown by the OR (0.642) meant that a good perception of perceived indoor air quality had 64.2% chance of ventilating adequately, with respect to homes perceiving very bad/bad/regular air quality.

The variable group related to comfort and energy use, was the one that showed the most relationship with the frequency of opening windows. One of them was the variable of thermal adaptation measures, which offered a significant relationship at the variable level, while its significant category was opening/closing windows (1.446). For every two households that changed clothes as a priority

Table 5
Odd Ratios (ORs) for the model on the dependent variable "frequency of opening windows before the pandemic".

Variable	Model parameters		
	B	Sig.	e^b
Current job situation			
Enterpreneur/self-employed	0.192	0.281	1.212
Employee	–		–
Living with elders (65+)			
No	–	0.092	–
Yes	0.399		1.491
Living with minors			
No	0.077	0.668	1.080
Yes	–		–
Living with minors (6–11 years old)			
No	0.390	0.105	1.477
Yes	–		–
Dwelling type			
Flat	0.218	0.268	1.244
House	–		–
Own external space			
No	–	0.213	–
Yes	0.207		1.230
Orientation: West			
No	0.239	0.190	1.270
Yes	–		–
Perceived Indoor Air Quality (IAQ)		**<0.001****	
Very bad/bad/regular	–		–
Good	−0.443	**0.048***	0.642
Very good	0.156	0.529	1.169
Perceived lighting quality		0.070	
No/little adequate	–		–
Adequate	−0.128	0.690	0.880
Very adequate	−0.060	0.854	0.941
Totally adequate	0.388	0.269	1.474
Habitual clothing in the home		0.458	
Light	0.327	0.220	1.387
Normal	0.253	0.274	1.288
Heavy	–		–
Thermal preferences indoors		0.302	
Hotter	–		–
No change	−0.109	0.587	0.896
Cooler	0.214	0.418	1.238
Thermal adaptation measures		**0.021***	
Cloths change	–		–
Open/Close windows	0.369	**0.024***	1.446
Turn on/off heating system	−0.303	0.236	0.739
Heating System		**<0.001****	
None	0.138	**<0.001****	1.147
Individual (by room/dwelling)	0.138	0.077	0.138
Collective (by building, district, etc)	–		–
Energy source of Domestic Hot Water		**0.032***	
Natural gas	–		–
Power	0.467	**0.009****	1.596
Gasoil	0.149	0.596	1.160
Sensitivity and specificity	Sensitivity		Specificity
	40.1		85.0
Statistics of Model Adjust	−2 log verosimil.	R2 Cox and Snell	R2 Nagelkerke
	1151.268	0.116	0.156

*The level of significance is set at *Ns < 0.05, and **Ns < 0.01, for a CI ≥ 95%. Bolds indicate the significant relation.

measure for thermal adaptation and adequately ventilated, there were three opening and closing the windows adequately to adapt the dwelling. The next variable associated was the heating system, both at a variable level, and for the category "no heating system" (OR 1.147), where for every 10 homes with collective heating and adequate ventilation, simultaneously there were more than 11 homes without heating, ventilating with similar frequencies. Finally, of this group of variables, the energy source for heating domestic hot water (DHW) also showed a significant relationship at the variable level, and at the category level, for power energy. Therefore, according to the OR obtained (1.596), for every five households that used natural gas to heat water and ventilate adequately, there were eight households using power and ventilating in the same way. This category obtained the highest logit of the entire model, showing the strongest relationship.

3.5. Multivariate model for the dependent variable "ventilation frequency during pandemic"

Following the formula in subsection 3.4, the hypothesis established for the second and third models, had the dummy dependent variable "frequency of opening windows during the lockdown", which presented the success case (1) for the category "adequate ventilation". Table 6 reflects the results of the binary logistic regression model, with the independent variables that showed significant relationships in the previous bivariate analysis, related to general variables.

Among the general variables, or characteristics of households and dwellings, one of those that were significantly associated was the current employment situation. For each home with the presence of self-employed workers or entrepreneurs ventilating adequately, there were almost twice as many in which there were employees ventilating the same way.

In the subgroup of housing comfort and energy aspects, two variables showed a significant relationship. One of them was the usual clothing at home, where the category that reflected this relationship was warm clothing (OR 2.356). This indicator establishes that for each cohabiting nucleus that used light clothing and ventilated adequately, there were almost 2.5 households dressing warmly when ventilating in the same way. This logit was the largest of the multivariate relationship table during the pandemic, in terms of overall independent variables (Table 6).

As the last significant variable in this table, the one related to the thermal adaptation measures was shown. In this case, the OR (2.239) indicates that for each household that opted for a change of clothes to adapt thermally by ventilating adequately, more than twice as many households resorted to opening/closing windows for the same purpose, with a similar frequency. This category also

Table 6
Odd Ratios (ORs) for the dependent variable "frequency of opening windows in confinement, having been poor before pandemic. General variables".

Variable	Model parameters		
	B	Sig.	e^b
Current job situation			
Enterpreneur/self-employed	–		–
Employee	0.632	**0.006****	1.880
Living with elders (65+)		0.056	
No	0.620		1.859
Yes	–		–
Dwelling type		0.171	
Flat	0.304		1.355
House	–		–
Own external space		0.630	
No	0.097		1.102
Yes	–		–
Orientation: West			
No	–		–
Yes	0.353	0.107	1.423
Habitual clothing in the home		**0.024***	
Light	–		–
Normal	0.211	0.328	1.234
Heavy	0.857	**0.007****	2.356
Thermal preferences indoors		0.315	
Hotter	–		–
No change	−0.034	0.885	0.967
Cooler	0.409	0.240	1.506
Thermal adaptation measures		**<0.001****	
Cloths change	–		–
Open/Close windows	0.806	**<0.001****	2.239
Turn on/off heating system	−0.351	0.188	0.704
Use frequency of Heating System		0.093	
Never/barely	0.445	0.081	1.561
Only if necessary	0.004	0.987	1.004
Frenquently/Continuously	–		–
Sensitivity and specificity	Sensitivity		Specificity
	84.2		35.3
Statistics of Model Adjust	−2 log verosimil.	R2 Cox and Snell	R2 Nagelkerke
	747.559	0.092	0.124

*The level of significance is set at *Ns < 0.05, and **Ns < 0.01, for a CI ≥ 95%. Bolds indicate the significant relation.

presented one of the highest logits in significant relationships.

Below, Table 7 represents those relations maintained among dependent variable "window opening frequency during confinement, being poor ventilated before", with independent variables linked to activities and habit changes associated to be confined, such as teleworking compared use of kitchen appliances, habit changes and desire of housing improvement.

This third logistic regression model, the second for the variable of frequency of window opening during quarantine (for households that had poor ventilation before), focused on the relationships with variables of activities or habits linked to confinement itself. Specifically, the multivariate significant relationships were: the compared use of the oven, the alteration of habits related to work, and sports, and enjoying the outside environment.

The comparative use of the oven presented significance as a variable, but also at the level of the category "more use than usual", whose logit far exceeded all those in the observed models. Indeed, with an OR = 14,809, for each household that used the oven in

Table 7
Odd Ratios (ORs) for the model on the dependent variable "frequency of opening windows during confinement, having been poor, before the pandemic. Variables related to activities and habits in confinement".

Variable	Model parameters		
	B	Sig.	e^b
Type of teleworking space			
Itinerant or occasional shared space	0.418	0.077	1.519
Previous shared or exclusive space	–		–
Adequate room size			
No	–	0.489	–
Yes	0.180		1.197
Adequate surface finishing			
No	–	0.925	–
Yes	0.022		1.022
Compared use of stoves		0.127	
Less use than usual	22.355	1.000	5×10^9
Same use as usual	−0.594	0.042	0.552
More use than usual	–		–
Compared use of oven		**0.008****	
Less use than usual	–		–
Same use as usual	1.962	0.127	7.114
More use than usual	2.695	**0.039***	14.809
Compared use of kitchen robot		0.322	
Less use than usual	0.939	0.156	2.557
Same use as usual	0.239	0.366	1.270
More use than usual	–	–	–
Working			
No	0.990	**0.017***	2.691
Yes	–	–	–
Cleaning			
No	–		–
Yes	0.250	0.340	1.284
Domestic chores			
No	–		–
Yes	0.088	0.756	1.092
Clothing change			
No	0.233	0.310	1.263
Yes	–	–	–
Sports			
No	–		–
Yes	0.584	**0.013***	1.793
Enjoy the external space			
No	–		–
Yes	0.470	**0.043***	1.600
Desire for insulation improvement			
No	–		–
Yes	0.332	0.169	1.394
Changes in housing (5 or more)			
No	–		–
Yes	0.265	0.589	1.303
Home satisfaction (essential features)			
No	–		–
Yes	0.185	0.706	1.203
Sensitivity and specificity	Sensitivity 40.6		Especificity 84.0
Statistics of Model Adjust	−2 log verosimil. 495.096	R2 Cox and Snell 0.122	R2 Nagelkerke 0.165

*The level of significance is set at *Ns < 0.05, and **Ns < 0.01, for a CI ≥ 95%. Bolds indicate the significant relation.

confinement less than usual, ventilating adequately, 14 households used more this appliance, with the same frequency of window opening.

Regarding the perception of habit alteration during lockdown, those households that declared seeing the working aspect altered were 2.7 times more than those that did not declare it, belonging in both cases to those to those ventilating adequately.

Likewise, those who declared that their sporting habit had changed accounted for almost 2 (1793) times more households than those who did not declare it, both being households ventilating with adequate frequency.

Lastly, those households stating that their habits of enjoying outdoor activities (in outdoor space) had been altered and that they ventilated frequently, were 1.6 times more than those that, ventilating in the same way, did not observe changes in terms of the relationship with the external environment.

Similarly, those who declared that their sport habit had changed accounted for almost 2 (1793) times more households than those who did not declare it, both cases being households ventilating with adequate frequency.

4. Discussion

Observing the bivariate relationships, workers who could stay at home longer in the dwelling, presented adequate ventilation frequencies, compared to those who working as employees. The presence of older people and minors was related to frequencies poor window opening, which could be explained by a matter of security in the home, especially when it comes to avoiding accidents [26].

On a regular basis, the most frequent window opening was related to the dwelling type, specifically single-family homes. Flats were related to poor ventilation.

Dwellings with a total or partial orientation with a west component tended to ventilate less regularly. Taking into account the Spanish latitude, it could be presumed that there is a certain bias in this response, where a house with a west component is usually not sunny until the afternoon, so they are cold houses, and therefore, they required more heating use than a house with a south or east component, for instance Ref. [27]. Therefore, if there was a higher demand for heating, opening windows could be avoided to be more energy-efficient.

Among homes that ventilated the best, there were those with the greatest need to ventilate (due to humidity or charged environment) and those who already considered their indoor air to be of high quality, perhaps as an effect of their own habit of often opening windows [28]. The relationship with the quality of perceived general lighting (both natural and artificial) was related in a polarized way with the frequency of natural ventilation. This may be due to the fact that those who opened the windows more, could be either homes that had a greater need to illuminate their rooms, or those in which the effect of opening the windows resulted in high-quality lighting or to enjoy the views [29–32].

Those who habitually ventilated the most, tended to get dressed lightly or normally, compared to those who dressed warmly at home. This might be related to the hypothesis of bias due to the pre-pandemic winter period, which, together with colder dwellings (by orientation, lack of sunlight due to the building's own or remote obstacles, or other reasons), and in its case due to a greater need for heating, they bundled up and therefore avoided opening windows so as not to have greater thermal demands. Those with better natural ventilation frequencies did not use fossil energy to heat water; instead, they used power energy.

When observing the ventilation frequency response in confinement of those who had habitually ventilated poorly, some reasoning was altered by what such a radical and disruptive change in activity and habits entailed [6]. As an example of this, in this period of confinement, those who ventilated the best were those employed by others. As was mentioned in the pre-pandemic period, although self-employed or entrepreneurs, being able to remain teleworking at home, could be the ones who ventilated the most, those who did not do so before the pandemic, remained the same habit during confinement. But those who usually worked outside, by staying at home teleworking, ventilated more, as highlighted relevant international organizations as International Labour Organization (ILO) [33].

Another of the relationships that were altered with the frequency of natural ventilation was the presence of people over 65 at home, which was related to less ventilation. Although during confinement it was advised to ventilate homes, the fear of contagion among the elderly, as a vulnerable group, by COVID-19, or other viruses, such as colds, or flu, could lead to closing the windows.

During confinement, the most ventilated homes were the flats, because they had a greater relationship with the outside world. Those dwellings without their own outdoor space. ventilated more adequately during confinement. This could be due to a need for outside contact, as well as a higher level of overcrowding.

This greater presence of cohabitants in the home, could make, due to the orientation of the west component, together with the progressive entry of spring, more necessary to ventilate frequently than for other orientations.

Only those who were thermally comfortable, were related to poor ventilation. This can be explained by the use of heating systems, since those who used heating the most, ventilated poorly. However, the relationship of ventilating frequently was maintained between those who chose it as a priority adaptation measure and those who preferred to be cooler.

The largest opening of windows occurred in teleworking spaces shared circumstantially or itinerant. This could be explained by a greater presence of cohabitants (because of care, above all) in spaces of this nature. However, those accustomed to teleworking, or to using exclusive spaces in the home for these tasks, did not ventilate well beforehand.

These hypotheses about the most open and largest spaces, and with a greater presence of cohabitants, are confirmed by the fact that the households most satisfied with the size of the teleworking space were the ones that ventilated the best. Similarly, those with better surface finishes, also ventilated better, which can also be related to this type of space, traditionally more social, more cared for, and thus, more pleasant to stay working, as were dining and living rooms [34,35].

With respect to other activities during confinement, increased culinary activity (what reflected the increasing demand on domestic energy supply in lockdown) [36], was related to a higher frequency of ventilation during confinement. This opens the possibility that it was not only due to the greater presence of cohabitants, but also to the need to exchange air with the outside, also by the effect of the heat produced, in the case of the oven, or to the odours generated (which would explain, for example, the case of kitchen robots) [37].

Some of the behavioural changes that have been linked to a greater frequency of opening windows, such as work and lack of contact with nature, warranted more ventilation. But also, the alteration of domestic tasks, including cleaning, in addition to having to ventilate to release possible chemical products, among others, also needed ventilation.

People who want more insulation in their home, ventilated more frequently, and those who want 5 or more aspects to change in the dwelling, ventilated less frequently. This could be related to urban environments, with smaller flats, where families lived in a higher proportion by renting, and presented less capacity for change in design and construction aspects [38].

In the logistic regression model, the strongest relationships were established for the perception of good air quality, measures of thermal adaptation, and energy aspects, such as the unavailability of heating and the electrical source of energy for hot water. This confirms that the adequate opening of windows on a regular basis, that is, in an almost cultural or intrinsic way to the habit of ventilating, depends not only on having a good perception of air quality (in terms of air that is not stale, odourless or charged), but also of its traditionally intrinsic but inverse relation to thermal comfort. Since, if this depended on a demand solved with a heating system, opening the windows would waste energy by losing previously treated air in the exchange with the outside [37]. This could be solved with an increase in hybrid air conditioning systems (hot/cold) and mechanical or hybrid ventilation incorporated in the system, so that they do not have to choose between thermal comfort and indoor air quality [39].

The thermal adaptation of opening/closing windows is an option that was positioned as contrary to turning the heating system on/off, or using clothing to self-regulate thermal comfort [40]. Lastly, the perception of energy efficiency, seemed to extend to the ways of consuming energy to heat water for domestic use, since those fuel sources interfered with the opening of windows.

As for the regression models related to the period of confinement, forced permanence in the dwelling, which resulted teleworking for many households, also generally altered the way of ventilating. Clothing also affected, since those who warmed up more, opened the windows more frequently. So, it is understood, together with the multivariate relationship of the adaptation measures, that those households that regulated by opening/closing windows, had no problem staying warmed more than necessary, and they opened despite the thermal comfort. There is therefore a different discourse for homes that mainly opted for achieving thermal comfort, and for those focused on ventilation and air quality. This debate has been very important for the re-conceptualization of Spanish regulations in terms of energy and health, which has traditionally focused on the progressive search for energy savings and efficiency in the home, while gradually losing air permeability towards a progressive housing- sealing for the newest projects. The latest regulatory revisions have taken both aspects into account, and propose mechanical or hybrid ventilation systems, so as to compensate for the greater thermal insulation of both opaque enclosures and opening systems, including carpentry [13,14]. However, the big problem persists in existing homes [12] which, as already mentioned, in Spain are more than 90%, with poor levels of thermal comfort and insulation [15], and that, despite being candidates for national and European fundings [41,42], many of them are limited to technical responses of insulation from the outside, and/or change of windows, but they do not solve the problem of air infiltrations, nor the control by ventilation systems that might ensure a correct balance with possible support air conditioning equipment.

Although it is necessary to tend not to depend on energy, on the other hand, the support of systems that guarantee the well-being and health of people, especially vulnerable groups, translates into responding to moments of thermal discomfort, to avoid problems not only from thermal discomfort, but also from energy poverty, especially in the face of expectations such as the scenarios foreseen for 2050 by the IPCC [43]. In this framework, and under the Sustainable Development Goals established by the United Nations (UN), some coupled with air conditioning systems and other new proposals based not only on natural ventilation have been suggested during the pandemic, as a less expensive alternative both in the initial investment and in its performance and maintenance. This also occurred to support initiatives with a lower economic, energy and environmental impact [44], although these solutions must be adapted to the type of space, and to the needs derived from the climatic environments of each place, paying attention to noise and any other energy expenditures associated [45]. Extreme weather events, such as heat and cold waves, are affecting severely the countries of southern Europe, including Spain [46]. In this sense, problems such as energy poverty can only get worse, and faced with this potentially increased problem, only technically and energy efficient solutions can be offered, if possible supported by renewable and clean energies, and with mechanically controlled ventilation support (or hybrids), which regulate the quality of the indoor air, so that people do not have to choose between thermal comfort and air quality, nor having to leave it in the hands of the presence and/or will of people, subject to cultural or behavioural issues [47].

The study has several limitations. In the first place, the selection of participants was made for convenience and therefore was not representative. On the other hand, the outbreak of the pandemic was abrupt and disruptive. The need to be able to count on the testimonies and opinions of people during the first wave, together with the problem of being able to carry out research face-to-face, gave it a great exploratory value, since there were also very few studies that addressed confinement during the initial phase of the pandemic, and in particular, bearing in mind that the home was the main refuge of the population[48].

Second, was derived by the very nature of studies based on online questionnaires, since not all people had access to the Internet. Although, in the case of Spain, 95.3% of the Spanish population in 2020 of households had Internet access [49].

Thirdly, the dependent variable related to poor or adequate ventilation was a qualitative or categorical variable constructed from five original categories corresponding to the frequency of opening/closing windows, which was requested both for the "before" of the confinement, as for the "during" (lockdown). These categories were: "Continuously open", "Several times a day", "Once a day", "Sometimes a week", "Continuously closed". The authors understand that this variable has limitations due to its qualitative nature, since the ideal situation would have been, to be able to count on monitored data, or to have made a specific questionnaire on ventilation (at least, with some questions on frequency in terms of time opened, distribution in weekdays/weekends, etc). However, authors also understand that this basic information, combined with other data on thermal comfort, energy consumption, and behavioural and sociodemographic patterns, could offer valuable information corresponding to a crucial moment in the life of Spanish households and their adaptive capacity to extreme events, such as a general lockdown.

Other limitation was not to consider external environmental aspects, such as meteorological events or noise annoyance to explain potential causes to window opening/closing patterns. This fact is based on two reasons: first, the overall character of this questionnaire, with no specific questions about window-related aspects; and second, the level of external noise decreased during pandemic, so the noise annoyance in this case seemed not to be relevant in this period. But obviously, those aspects usually affect households' patterns on window opening.

The last limitation is derived from the lack of mechanical/hybrid ventilation systems in the most of the Spanish current housing stock. For this reason, indications on the many advantages of these kind of systems, such as to control airborne SARS-CoV-2 transmission, have not been included in this manuscript. Nevertheless, this advantage and many others have to be highlighted, encouraging their installation, to control the indoor air quality.

5. Conclusions

Opening the windows is a simple action, but obeys a complex reflection, based on multiple potential reasons, just like the fact of not opening them. It is not just a behavioural or cultural issue. The reasons that may lead a home to open the windows more or less frequently may not even be intuitive, or not entirely, being conditioned by the need or the culture of natural ventilation. A poor air quality, adaptive thermal measures, the lack of heating systems, and the sources to heat water, were reasons to determine the window opening frequency.

However, the disruptive event of home confinement due to COVID-19, implied a change in routines and habits, and a significant increase in the presence of all members at home at the same time (even sharing spaces for a protection, care, surveillance or need). With this, the criteria of indoor environmental quality, specially ventilation, were also conditioned by the presence of people, as well as by the deprivation of contact with the outside and nature.

This led to value the windows as elements of connection with that exterior and with natural elements (gardens, parks or nearby trees), which were altered according to the need for contact of the cohabitants, also subject to the needs of thermal comfort and changing weather. The very presence of people also led to opening the windows to compensate the lack of fresh air, promoting exchange air with the outside. The concentration of activities indoors, especially those requiring a higher level of concentration, and the generation of greater thermal loads (especially latent, such as sports), or others that physically require air drafts to speed up its completion (such as surface cleaning, for example), also affected this natural ventilation pattern.

But one of the most underlying issues is how natural ventilation is subject to criteria for the use of thermal energy, above all, and to the perception of comfort and how each home uses thermal adaptive options. These issues would be solved, at least to a large extent, if hybrid or mechanical ventilation systems would be integrated into hot/cold air conditioning systems in the homes, as required in the most recent building regulations. However, this is not reflected in the existing residential stock, almost entirely prior to these regulations, and which can only be ventilated naturally. For these cases, a comprehensive rehabilitation strategy is needed, that also integrate, when necessary, controlled ventilation mechanisms to ensure indoor air quality.

Funding

This research was funded by Consejo Superior de Investigaciones Científicas (CSIC), grant number 202060E225, entitled: "Proyecto sobre confinamiento social (COVID-19), vivienda y habitabilidad [COVID-HAB]".

Credit author statement

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that have been used are confidential.

Acknowledgements

The authors want to thank the CIBERESP of the Instituto de Salud Carlos III (Spain) for access to the online data collection platform in this study. Also, they appreciate the contribution from Aplica Coop. with the data analysis. And, of course, to every single household participant.

References

[1] World Health Organization, Director-General's opening remarks at the media briefing on COVID-19. https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19–11-march-2020. (Accessed 11 October 2020).
[2] F. Amer, S. Hammoud, B. Farran, I. Boncz, D. Endrei, Assessment of countries' preparedness and lockdown effectiveness in fighting COVID-19, Disaster Med. Public Health Prep. 15 (2) (2021) E15–E22, https://doi.org/10.1017/dmp.2020.217.
[3] M. Pollán, B. Pérez-Gómez, R. Pastor-Barriuso, J. Oteo, M.A. Hernán, M. Pérez-Olmeda, J.L. Sanmartín, A. Fernández-García, I. Cruz, N. Fernández de Larrea, M. Molina, F. Rodríguez-Cabrera, M. Martín, P. Merino-Amador, J. León Paniagua, J.F. Muñoz-Montalvo, F. Blanco, R. Yotti, R. Gutiérrez Fernández, S. Mezcua Navarro, J.F. Muñoz-Montalvo, M. Salinero Hernández, J.L. Sanmartín, M. Cuenca-Estrella, J. León Paniagua, P. Fernández-Navarro, A. Avellón, G. Fedele, J. Oteo Iglesias, M.T. Pérez Olmeda, M.E. Fernandez Martinez, F.D. Rodríguez-Cabrera, M.A. Hernán, S. Padrones Fernández, J.M. Rumbao Aguirre, J. M. Navarro Marí, B. Palop Borrás, A.B. Pérez Jiménez, M. Rodríguez-Iglesias, A.M. Calvo Gascón, M.L. Lou Alcaine, I. Donate Suárez, O. Suárez Álvarez, M. Rodríguez Pérez, M. Cases Sanchís, C.J. Villafáfila Gomila, L. Carbo Saladrigas, A. Hurtado Fernández, A. Oliver, E. Castro Feliciano, M.N. González Quintana, J.M. Barrasa Fernández, M.A. Hernández Betancor, M. Hernández Febles, L. Martín Martín, L.M. López López, T. Ugarte Miota, I. De Benito Población, M.S. Celada Pérez, M.N. Vallés Fernández, T. Maté Enríquez, M. Villa Arranz, M. Domínguez-Gil González, I. Fernández-Natal, G. Megías Lobón, J.L. Muñoz Bellido, P. Ciruela, A. Mas i Casals, M. Doladé Botías, M.A. Marcos Maeso, D. Pérez del Campo, A. Félix de Castro, R. Limón Ramírez, M.F. Elías Retamosa, M. Rubio González, M.S. Blanco Lobeiras, A. Fuentes Losada, A. Aguilera, Y. Bou, G.; Caro, N. Marauri, L.M. Soria Blanco, I. del Cura González, M. Hernández Pascual, R. Alonso Fernández, N. Cabrera Castro, A. Tomás Lizcano, C. Ramírez Almagro, M. Segovia Hernández, N. Ascunce Elizaga, M. Ederra Sanz, C. Ezpeleta Baquedano, A. Bustinduy Bascaran, S. Iglesias Tamayo, L. Elorduy Otazua, R. Benarroch Benarroch, J. Lopera Flores, A. Vázquez de la Villa, Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study, Lancet 396 (10250) (2020) 535–544, https://doi.org/10.1016/S0140-6736(20)31483-5.
[4] Gobierno de España. Real Decreto 463/2020, de 14 de marzo, por el que se declara el estado de alarma para la gestión de la situación de crisis sanitaria ocasionada por el COVID-19.
[5] O.O. Odusanya, B.A. Odugbemi, T.O. Odugbemi, W. Ajisegiri, COVID-19: a review of the effectiveness of non-pharmacological interventions, Niger. Postgrad. Med. J. 27 (4) (2020) 261, https://doi.org/10.4103/npmj.npmj_208_20.
[6] M.Á. Navas-Martín, J.A. López-Bueno, I. Oteiza, T. Cuerdo-Vilches, Routines, time dedication and habit changes in Spanish homes during the COVID-19 lockdown. A large cross-sectional survey, Int. J. Environ. Res. Publ. Health *18* (22) (2021), 12176, https://doi.org/10.3390/ijerph182212176.
[7] B. Ganesh, T. Rajakumar, M. Malathi, N. Manikandan, J. Nagaraj, A. Santhakumar, A. Elangovan, Y.S. Malik, Epidemiology and pathobiology of SARS-CoV-2 (COVID-19) in comparison with SARS, MERS: an updated overview of current knowledge and future perspectives, in: Clinical Epidemiology and Global Health, Elsevier B.V, 2021, p. 100694, https://doi.org/10.1016/j.cegh.2020.100694. April 1.
[8] R. Read, Scientists say WHO ignores the risk that coronavirus floats in air as aerosol, in: Los Angeles Times, Blackwell Publishing Inc, Los Angeles, July 4, 2020, https://doi.org/10.1111/risa.13500.
[9] World Health Organization, Roadmap to Improve and Ensure Good Indoor Ventilation in the Context of COVID-19, 2021. Geneva.
[10] Gobierno de España, Recomendaciones para cuidadores y familiares de personas mayores o vulnerables. https://www.sanidad.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov/img/COVID19_Cuidadores_mayores.jpg. (Accessed 10 February 2022).
[11] Gobierno de España, Las 6M siempre en mente. https://www.sanidad.gob.es/profesionales/saludPublica/ccayes/alertasActual/nCov/documentos/Infografia_6M.pdf. (Accessed 27 April 2022).
[12] C. Dimitroulopoulou, Ventilation in European dwellings: a review, Build. Environ. Pergamon (January 1, 2012) 109–125, https://doi.org/10.1016/j.buildenv.2011.07.016.
[13] Gobierno de España, Documento Básico HS, 2019.
[14] Gobierno de España, *Real Decreto 1027/2007, de 20 de Julio, Por El Que Se Aprueba El Reglamento de Instalaciones Térmicas En Los Edificios*; Ministerio de la Presidencia, 2007.
[15] España, De La Estrategia a Largo Plazo Para La Rehabilitación Energética En El Sector de La Edificación En España (ERESEE), 2020.
[16] World Health Organization, Roadmap to Improve and Ensure Good Indoor Ventilation in the Context of COVID-19, 2021. Geneva.
[17] J. Huang, P. Jones, A. Zhang, S.S. Hou, J. Hang, J.D. Spengler, Outdoor airborne transmission of coronavirus among apartments in high-density cities, Front. Built Environ. 48 (2021), https://doi.org/10.3389/fbuil.2021.666923, 7.
[18] D.R. Culqui, J. Díaz, A. Blanco, J.A. Lopez, M.A. Navas, G. Sánchez-Martínez, M.Y. Luna, B. Hervella, F. Belda, C. Linares, Short-term influence of environmental factors and social variables COVID-19 disease in Spain during first wave (Feb–May 2020), Environ. Sci. Pollut. Res. 1 (3) (2022), https://doi.org/10.1007/s11356-022-19232-9.
[19] K. Ahmad, S. Erqou, N. Shah, U. Nazir, A.R. Morrison, G. Choudhary, W.-C. Wu, Association of poor housing conditions with COVID-19 incidence and mortality across US Counties, PLoS One 15 (11) (2020), e0241327, https://doi.org/10.1371/journal.pone.0241327.
[20] H. Qian, T. Miao, L. Liu, X. Zheng, D. Luo, Y. Li, Indoor transmission of SARS-CoV-2, Indoor Air 31 (3) (2021) 639–645, https://doi.org/10.1111/ina.12766.
[21] M. Zarrabi, S.A. Yazdanfar, S.B. Hosseini, COVID-19 and healthy home preferences: the case of apartment residents in tehran, J. Build. Eng. 35 (2021), 102021, https://doi.org/10.1016/j.jobe.2020.102021.
[22] T. Peters, A. Halleran, How our homes impact our health: using a COVID-19 informed approach to examine urban apartment housing, Archnet-IJAR 15 (1) (2021) 10–27, https://doi.org/10.1108/ARCH-08-2020-0159.
[23] Y. Huang, Q. Wu, P. Wang, Y. Xu, L. Wang, Y. Zhao, D. Yao, Y. Xu, Q. Lv, S. Xu, Measures undertaken in China to avoid COVID-19 infection: internet-based, cross-sectional survey study, J. Med. Internet Res. (May 1, 2020), e18718, https://doi.org/10.2196/18718. JMIR Publications Inc.
[24] L.E. Smith, H.W.W. Potts, R. Amlôt, N.T. Fear, S. Michie, G.J. Rubin, COVID-19 and ventilation in the home; investigating peoples' perceptions and self-reported behaviour (the COVID-19 rapid survey of adherence to interventions and responses [CORSAIR] study), Environ. Health Insights (May 14, 2021) 1–2, https://doi.org/10.1177/11786302211015588. SAGE Publications Inc.
[25] S. Torresin, R. Albatici, F. Aletta, F. Babich, T. Oberman, J. Kang, Associations between indoor soundscapes, building services and window opening behaviour during the COVID-19 lockdown, Build. Serv. Eng. Technol. 43 (2) (2022) 225–240, https://doi.org/10.1177/01436244211054443.
[26] E. Dolgun, A. Kalkım, S. Ergün, The determination of home accident risks and measures to prevent accident of children: quasi-experimental research, Turkish J. Fam. Med. Prim. Care 11 (2) (2017) 100, https://doi.org/10.21763/tjfmpc.317852, 100.
[27] V. Olgyay, in: Arquitectura y Clima: Manual de Diseño Bioclimatico Para Arquitectos y Urbanistas, 1998th ed., 1962. Barcelona.
[28] J. Wang, D. Norbäck, Subjective indoor air quality and thermal comfort among adults in relation to inspected and measured indoor environment factors in single-family houses in Sweden-the BETSI study, Sci. Total Environ. 802 (2022), 149804, https://doi.org/10.1016/j.scitotenv.2021.149804.
[29] Y. Meesters, K.C.H.J. Smolders, J. Kamphuis, Y.A.W. De Kort, Housing, natural light and lighting, greenery and mental health, Tijdschr Psychiatr 62 (7) (2020) 555–563.
[30] A.M. Dzhambov, P. Lercher, M.H.E.M. Browning, D. Stoyanov, N. Petrova, S. Novakov, D.D. Dimitrova, Does greenery experienced indoors and outdoors provide an escape and support mental health during the COVID-19 quarantine? Environ. Res. (2020), 110420 https://doi.org/10.1016/j.envres.2020.110420.
[31] T. Cuerdo-Vilches, M.Á. Navas-Martín, Confined students: a visual-emotional analysis of study and rest spaces in the homes, Int. J. Environ. Res. Publ. Health 18 (11) (2021) 5506, https://doi.org/10.3390/ijerph18115506.
[32] C. Muñoz-González, J. Ruiz-Jaramillo, T. Cuerdo-Vilches, M.D. Joyanes-Díaz, L. Montiel Vega, V. Cano-Martos, M.Á. Navas-Martín, Natural lighting in historic houses during times of pandemic. The case of housing in the mediterranean climate, Int. J. Environ. Res. Publ. Health 18 (14) (2021) 7264, https://doi.org/10.3390/ijerph18147264.
[33] International Labour Organization, Safe Return to Work: Ten Action Points, 2020.
[34] T. Cuerdo-Vilches, M.Á. Navas-Martín, I. Oteiza, Working from home: is our housing ready? Int. J. Environ. Res. Publ. Health 18 (14) (2021) 7329, https://doi.org/10.3390/ijerph18147329.

[35] M. Jaimes Torres, M. Aguilera Portillo, T. Cuerdo-Vilches, I. Oteiza, M.Á. Navas-Martín, Habitability, resilience, and satisfaction in Mexican homes to COVID-19 pandemic, Int. J. Environ. Res. Publ. Health 18 (13) (2021) 6993, https://doi.org/10.3390/ijerph18136993.
[36] T. Cuerdo-Vilches, M.Á. Navas-Martín, I. Oteiza, Behavior patterns, energy consumption and comfort during COVID-19 lockdown related to home features, socioeconomic factors and energy poverty in madrid, Sustainability 13 (11) (2021) 5949, https://doi.org/10.3390/su13115949.
[37] P. Wargocki, What we know and should know about ventilation. https://www.rehva.eu/rehva-journal/chapter/what-we-know-and-should-know-about-ventilation. (Accessed 15 May 2022).
[38] M.Á. Navas-Martín, I. Oteiza, T. Cuerdo-Vilches, Dwelling in times of COVID-19: an analysis on habitability and environmental factors of Spanish housing, J. Build. Eng. 60 (2022), 105012, https://doi.org/10.1016/j.jobe.2022.105012.
[39] M. Özdamar, F. Umaroğulları, Thermal comfort and indoor air quality, Int. J. Sci. Res. Innov. Technol. 5 (3) (2018) 90–109.
[40] F. Nicol, M. Humphreys, S. Roaf, Adaptive thermal comfort: principles and practice, Taylor and Francis (2012), https://doi.org/10.4324/9780203123010.
[41] European Commission, He EU's 2021-2027 long-term budget and NextGenerationEU, Facts and Figures. https://data.europa.eu/doi/10.2761/808559. (Accessed 16 May 2022).
[42] Gobierno de España, Plan de Recuperación, Transformación y Resiliencia. https://www.lamoncloa.gob.es/temas/fondos-recuperacion/Documents/160621-Plan_Recuperacion_Transformacion_Resiliencia.pdf. (Accessed 16 May 2022).
[43] IPCC, Climate Change, Impacts, Adaptation and vulnerability. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf. (Accessed 15 May 2022).
[44] M. Krarti, Integrated design and retrofit of buildings, in: Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers, Elsevier, 2018, pp. 313–384, https://doi.org/10.1016/b978-0-12-849869-9.00006-5.
[45] D. Aviv, K.W. Chen, E. Teitelbaum, D. Sheppard, J. Pantelic, A. Rysanek, F. Meggers, A fresh (air) look at ventilation for COVID-19: estimating the global energy savings potential of coupling natural ventilation with novel radiant cooling strategies, Appl. Energy 292 (2021), 116848, https://doi.org/10.1016/j.apenergy.2021.116848.
[46] M. Navas-Martín, J.A. López-Bueno, J. Díaz, F. Follos, J. Vellón, I. Mirón, M. Luna, G. Sánchez-Martínez, D. Culqui, C. Linares, Effects of local factors on adaptation to heat in Spain (1983–2018), Environ. Res. 209 (2022), 112784, https://doi.org/10.1016/j.envres.2022.112784.
[47] B.C. Singer, W.R. Chan, Y. Kim, F.J. Offermann, I.S. Walker, Indoor air quality in California homes with code-required mechanical ventilation, Indoor Air 30 (5) (2020) 885–899, https://doi.org/10.1111/ina.12676.
[48] T. Cuerdo Vilches, I. Oteiza San José, M.Á. Navas Martín, Proyecto sobre confinamiento social (covid-19), vivienda y habitabilidad [COVID-HAB], Paraninfo Digit 14 (2020) 32, e32066o.
[49] Instituto Nacional de Estadística. Nota de Prensa. Encuesta Sobre Equipamiento y Uso de Tecnologías de Información y Comunicación En Los Hogares, 2021.