Ventilation guidelines for Flemish childcare and psychological care centres

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ABSTRACT

Since the COVID-19 pandemic, governments have expressed the need for practical ventilation guidelines to maintain acceptable indoor air quality (IAQ) in the public care sector, where vulnerable groups reside. The aim of this paper is to establish such guidelines dedicated to old and newly built psychological care homes and child day care centres in Flanders (Belgium). For each sector, a representative simulation model was designed in Modelica. Inputs for building and system characteristics, and occupant behaviour were gathered via an online survey and assessed via a stakeholder group, representing each sector. Afterwards, multiple simulation scenarios, varying building and system characteristics (e.g., ventilation system type, control, flow rate, window opening area) and occupant behaviours (e.g., window opening frequency and duration, occupancy density) were tested. The impact of each simulation scenario on the CO_2-concentrations exceedance hours and energy use were evaluated. Based on the simulation results, appropriate ventilation strategies offering acceptable IAQ conditions were determined. Finally, the feasibility of each ventilation strategy was discussed with the stakeholder groups and the guidelines were translated into practical instructions for building facility managers in the public care sector of Flanders.

KEYWORDS

Ventilation guidelines, indoor air quality, energy use, care facilities, occupant behaviour

INTRODUCTION

Nowadays, individuals spend approximately 90% of their time indoors, engaging in daily activities for work or recreation. Thus, it is crucial that existing and newly constructed buildings prioritize the creation of optimal levels of indoor environmental quality, especially thermal comfort and indoor air quality (IAQ). This is even more imperative in the case of vulnerable groups having fragile or already compromised health, that spend even more time indoors and are most susceptible to building-related health outcomes. This includes infants and children in childcare centres, elderly people in retirement homes and disabled individuals in specialized care facilities. As recently evidenced by field measurements, questionnaires and clinical tests in 50 nursing homes across Europe, there is a direct relationship between respiratory symptoms and exposure to indoor air pollutants (Bentayeb et al., 2015). A meta-analysis of 10 European birth cohorts found associations between pneumonia in early childhood and exposure to pollutants (MacIntyre et al., 2014). This shows the vulnerability of current care facilities and the lack of proper ventilation measures put in place to protect its inhabitants.

Thus, indoor air pollution is a major global public health problem that requires increasing efforts in research and policy making, especially when it comes to the design and operation of existing ventilation systems. So far, EU standards recommend ventilation rates for human occupancy to satisfy certain indoor air classifications. This cannot always guarantee good IAQ under typical expected conditions and has proven itself to be completely insufficient in the face of disruptive events such as the COVID-19 pandemic. The latter had a great negative impact on care facilities world-wide which were already vulnerable. In Belgium alone, 42% of

COVID-19 deaths occurred in care facilities and nursing homes (Comas-herrera et al., 2020). Quick fix solutions in buildings with common gathering areas included increasing ventilation rates in tandem with a more vigorous monitoring of the IAQ. This yields an increase in energy usage (e.g., 15%) without a guarantee of improved IAQ at a time where saving energy is a priority in the EU (Krarti & Aldubyan, 2021; Pease et al., 2021). Moreover, such solutions are not an option for care facilities as most are public buildings with limited budgets. In these cases, facility managers often rely on counter-intuitive opening of windows and doors without paying much regard to the operation of building HVAC systems, energy usage, interzonal airflows, wind, type of rooms and activities. While such strategies can sometimes improve IAQ, they are often random and unreliable. Therefore, care facilities can benefit from clear and simple ventilation guidelines that can guarantee an acceptable level of IAQ without unnecessary energy usage throughout the year.

Thus, the aim of the current work is to establish in coordination with the Preventive Health Policy Division and the Flemish Infrastructure fund for personal affairs (VIPA) of the Flemish department of care ; ventilation guidelines for different types of care sectors in Flanders, Belgium: (i) elderly care homes, (ii) childcare facilities for children between 0 – 3 years of age, (iii) psychological care centres for mentally disadvantaged individuals, (iv) local service centres, (v) care centres for physically disabled individuals, and (vi) rehabilitation centres. These guidelines are meant to help facility managers of care sector buildings in their decision-making regarding facility operations. To reach this aim, a performance assessment of current ventilation designs in existing care facilities was conducted via simulations of representative cases of such buildings in Flanders. The assessment considered the realistic usage profile of the premises by conducting qualitative surveys across a wide range of care facilities in Flanders. The guidelines give simplified recommendations about the adequate opening of windows in tandem with the ventilation system while accounting for energy use. While the guidelines were established for different facility types and multiple space ventilation systems variations, for the sake of brevity, **the results that will be presented in this work will focus on childcare (CCC) and psychological care centres (PCC) and a mechanical exhaust system**.

METHODS

Firstly, a data collection campaign was performed to construct representative simulation models of the corresponding buildings. This was done by conducting surveys in each of the sectors to gather descriptive information pertaining to the usage of the buildings (i.e., occupancy schedules, activities, density, window usage and opening, ventilation systems) and analysing building plans to determine a representative typology (i.e., spaces and geometry, window locations). A literature study on existing national standards and legislation in each sector was conducted to gather information regarding current buildings and systems and make appropriate assumptions. Afterwards, meetings with stakeholders from each sector were organized to validate the initial assumptions. Secondly, the reference simulation models of the buildings were defined together with a set of simulation scenarios (e.g. variations in window opening schedules, size, occupancy densities, ventilation system operations) to conduct. The impact of each simulation scenario on the CO_2-concentrations exceedance hours and energy use was evaluated and ventilation guidelines were finally established from the simulation results. Though not the most representative indicator on cumulative exposure, the CO_2-concentrations exceedance hours was chosen due to its simplicity and to easily communicate the resulting guidelines with the stakeholders and personnel of the PCC and CCC.

Step 1: Data collection
Online surveys

Online surveys were distributed among technical personnel of PCC and CCCCC facilities. The survey aimed to gain year-round insights into (1) building and system characteristics (e.g., building age distribution, type of ventilation system and operation, solar shading and operation) and (2) occupant behaviour (e.g., occupancy schedules, window opening, control over heating and cooling setpoints). The surveys were designed and distributed via the software “Qualtrics” (Qualtrics, 2005). Stakeholders, representing multiple care facilities, distributed the survey among their members. In total, 25 and 31 respondents completed the surveys on their PCC or CCC facility, respectively. In the case of the PCC, the responses comprised 18 different facilities and 28 buildings. Figure 1a shows the results for the building construction year of both the PCC and CCC facilities. The distribution shows that both old and more recent buildings are commonly present in both facilities. Older constructions follow the older EPB standards before 2010 (Vlaanderen, 2006) while newer constructions follow the newer EPB standards that require a more energy performant building (Vlaanderen, 2022). These standards were used to model the building envelope characteristics.

Figure 1b presents the responses on the type of ventilation system present in the PCC facilities. A majority indicated that the facility was equipped with a balanced mechanical ventilation system with heat recovery (i.e., **MVHR**). The second highest response were respondents unsure about the ventilation system in their facility and respondents indicating that their facility was equipped with both a MVHR and mechanical exhaust ventilation (i.e., **MEV)**. In the facilities with both system types, the multi-occupied spaces were equipped with a MVHR, while the personal bedroom had a MEV. A minority of the respondents indicated that their facility lacked a mechanical ventilation system (no MV) or comprised of a hybrid system, combining natural and mechanical ventilation.

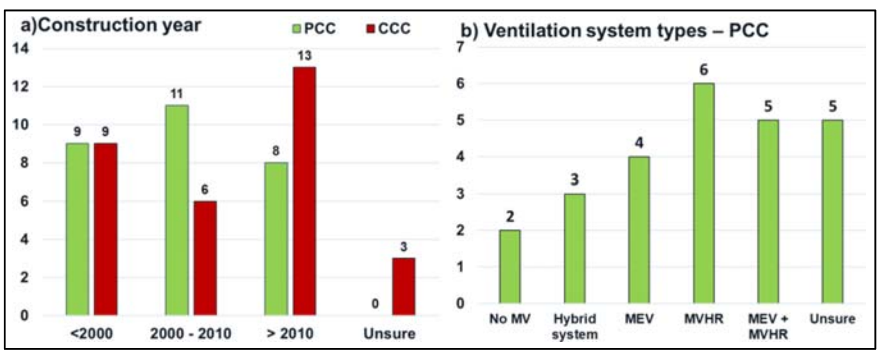

Figure 1. Survey results regarding a) building construction year, b) ventilation system types

Input from a large-scale survey in CCC facilities performed by VITO (Geyskens et al., 2023) was also used in the set-up of the reference simulation models. The results of the large-scale survey indicated that older CCC facilities were mostly not equipped with a mechanical ventilation system or equipped with an exhaust-only ventilation system (**MEV**). In newly built CCC facilities, exhaust-only or balanced mechanical ventilation system were present (**MEV, MVHR**). These systems were operated according to a schedule of 7:00 to 22:00.

In the PCC, the exhaust fans in the bathrooms connected to the sleeping rooms were always operated in case of occupancy in the bedrooms. In newer constructions, the smart humidity and CO_2 driven demand-controlled variable air volume (VAV) version of systems C and D could also be found (referred to as **MEV+ and MVHR+**) in common areas. In older and newer constructions of both CCC and PCC facilities, ventilation rates of 22 m^3/h and 36 m^3/h

per person were considered in the common rooms respectively. For the case of PCC, ventilation rates of 50 m^3/h and 75 m^3/h were considered in the bathrooms adjoint to the bedrooms in older and newer constructions respectively.

As for shading, for both CCC and PCC, older constructions were not equipped with any active solar shading device but rather overhangs and were not equipped with any cooling strategy. Newer CCC and PCC had automated external solar shading device and a split cooling end unit in common areas operated by the facility managers in case indoor temperatures exceed 26°C during hot summer months. According to the surveys, occupants had no control over the operation of the shading or cooling device. Radiators were used for heating in older and new constructions.

Table 1. Summary of ventilation systems and rates in a) PCC and b) CC

a) PCC sector		
	Old construction	**New construction**
Ventilation system types	MEV in all rooms with a ventilation rate of 22 m^3/h per person with fans operating between 7:00 – 22:00 in multi-occupied spaces. A ventilation rate of 50 m^3/h in WC adjoint to bedrooms via a door with grills. Fans operate during occupancy	MEV/MEV+, MVHR/MVHR+ in all rooms or MVHR/MVHR+ in multi-occupied spaces and MEV in sleeping rooms. Ventilation rate of 36 m^3/h per person in multi-occupied spaces operating between 7:00 – 22:00 for systems MEV/MVHR. CO_2-setpoint of 900ppm active in MEV+ and MVHR+. A ventilation rate of 75 m^3/h in WC adjoint to bedrooms via a door with grills. Fans operate during occupancy
b) CCC sector		
	Old construction	**New construction**
Ventilation system types	No mechanical ventilation (only window operation for ventilation)	MEV/MEV+, MVHR/MVHR+ in all rooms. Same rates per person as PCC and same control

Occupancy schedules varied depending on room usage and the type of sector. **Figure 2** shows representative occupancy schedules for PCC and CCC sectors. In the PCC, the common room had a maximum occupant density of 5 m^2 per person. It was in usage three times a day in the mornings, afternoons and evenings for three hours at a time. The dining room was used during mealtimes (breakfast, lunch, dinner) at a constant maximum occupancy density of 5 m^2 per person. The sleeping rooms were constantly occupied during nighttime and intermittently throughout the day depending on the preferences of occupants. In the PCC, occupants stayed regularly in their rooms. In the CCC, 9 children were allowed in one sleeping room at a time. The kids slept mostly in the afternoon for three hours. For the rest of the day, they were in the playing area in 2 groups at a time (18 children and 2 care takers). Parents would normally pick up their kids from 17:00 onwards.

Window opening was managed by the facility personnel and opening behaviours depended on the season and varied within the different sectors according to multiple scenarios. In winter season, windows were either kept closed most of the time, or opened 1 hour in the morning for the sake of ventilation. In multi-occupied areas, windows were also opened after peak activity hours to purge polluted air perceived as stuffy by occupants. In summer season, windows were opened more frequently. They were either open the whole day or closed during the day and open at night. **Table 2** shows the assumed window opening scenarios that are inclusive of the range of opening behaviour.

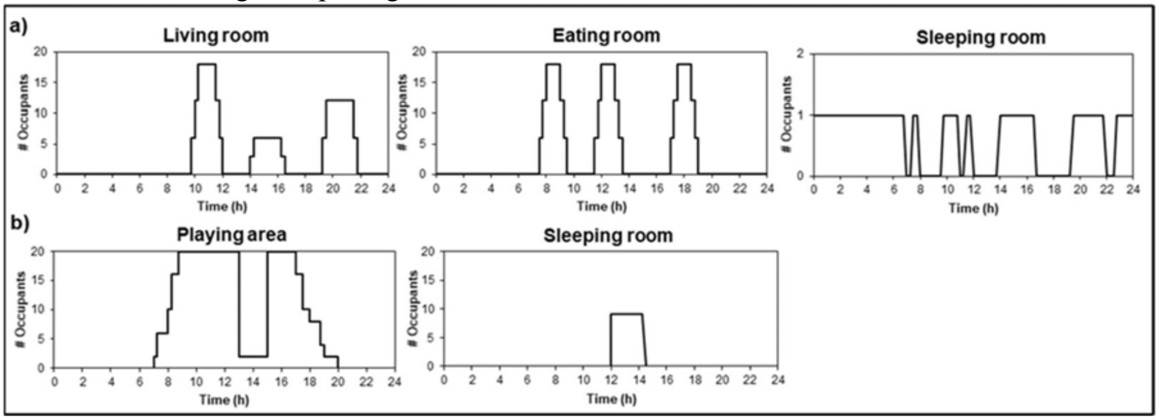

Figure 2. Occupancy schedules for a) PCC and b) CCC sectors

Table 2. Window opening scenarios: a) PCC and b) CCC sectors

a) PCC sector			
	Room type	**Heating season**	**Cooling season**
Scenario A	Common	Closed all day	Open at night
	Sleeping	Open 1h in the morning	Open at night
Scenario B	Common & sleeping	Open 1h in the morning	Full day open
Scenario C	Living	Open after activities for 1h	Open during the day, closed at night
	Eating	Open after meals for 1h	Open during the day, closed at night
	Sleeping	Open 1h in the morning	Open 1h in the morning
b) CCC sector			
		Heating season	**Cooling season**
Scenario 1	Common & sleeping	Closed all day	Closed all day
Scenario 2	Common	Open 1h in the morning	Open during activities
	Sleeping	Open 1h in the morning	Open 1h before and after occupancy
Scenario 3	Common	Open 1h in the morning and during activities	Open full day
	Sleeping	Open 1h in the morning and 1h before and after occupancy	Open full day
Scenario 4	Common & sleeping	Open full day	Open full day

Building plans

A set of building plans from representative psychological care homes (PCC) and childcare centres (CCC) were delivered by VIPA and analysed. In Belgium, older and new constructions are commonly present when it comes to the care sector. Thus, both were considered in the analysis of the building plans and the formulation of the guidelines. The analysis consisted of determining a representative layout and geometry of the different rooms of interest, window positioning and areas, building orientations and layouts. For the PCC sector, a representative layout of older and new constructions consists of a common area room used for recreation and oriented South (average conditioned floor area A_c of 90 m^2) with one external façade. It has south oriented manually operable windows with a window to floor ratio (WFR) of 7%. Opposite to it and connected by a narrow hallway is a dining room (A_c = 128 m^2) with one external façade having north oriented windows and a WFR of 16%. Located on either side of the hallway; are the residents' bedrooms with connected bathrooms (A_c = 20 m^2). The bedrooms have west-oriented windows with a WFR of 8%. As for the CCC, older constructions consist of a playing area (A_c = 54 m^2) and sleeping rooms (A_c = 22.5 m^2) with external façades facing south (WFR = 9%) and connected by an internal wall. Newly constructed CCCs have additionally an internal sleeping room (A_c = 22.5 m^2) connected to the playing area via a hallway.

Literature review

Current ventilation regulation requires that both residential and non-residential buildings in Belgium are equipped with a ventilation system capable of guaranteeing acceptable IAQ conditions, i.e., IDA class 3 in standard EN 13779 (European Committee for Standardization, 2007). However, practical guidelines on the operation of ventilation systems or opening of windows to maintain acceptable IAQ conditions are still missing. The Flemish decree on IEQ sets reference values for indoor temperature (Vlaamse Overheid, 2018). The decree advised an indoor temperature in multi-occupied spaces between 20°C-24°C and 22°C-26°C during heating and cooling season, respectively. The EPB guidelines were used to inform the building envelope construction (i.e., insulation, glazing, air tightness) for older and newer buildings in each sector. Since ventilation system design was based on CO_2, two thresholds are normally applied, i.e., 1200ppm and 900ppm. The first represented the maximum allowed CO_2-concentration during normal conditions. The latter corresponded to the target CO_2-concentration during normal circumstances and the maximum CO_2-concentration during periods of increased risk of respiratory infections (e.g., flu season, pandemic). Both thresholds were used as references levels for IAQ in Belgian legislation (Federale Overheidsdienst Werkgelegenheid - Arbeid en Sociaal overleg, 2022).

Step 2: Simulation models and performance assessment

Based on the building plans, existing guidelines and data collected from the online surveys, representative simulation models of the PCC and CCC sectors were developed using the Modelica language in the Dymola environment (Dassault Systèmes, 2024) as shown in **Figure 3**. The model was built using pre-validated components from the integrated district energy and systems (IDEAS) library (i.e., zones, envelope components, windows, HVAC systems)(Jorissen et al., 2018). Note that the window opening behaviour was modelled in Modelica with operable windows. The wind pressure coefficients were calculated using the correlation of (Swami & Chandra, 1987). Yearly simulations were conducted using the RADAUII solver with a time step of 15 minutes. The simulation scenarios included varying the ventilation systems and rates and window opening scenarios according to **Tables 1** and **2**. The IAQ was evaluated based on the CO_2-concentrations exceedance hours, which gave a percentage (%) of occupied time that the CO_2-concentrations were above the two thresholds.

The energy use (heating, cooling, fan electricity use) was also computed and used as a benchmark to formulate the guidelines.

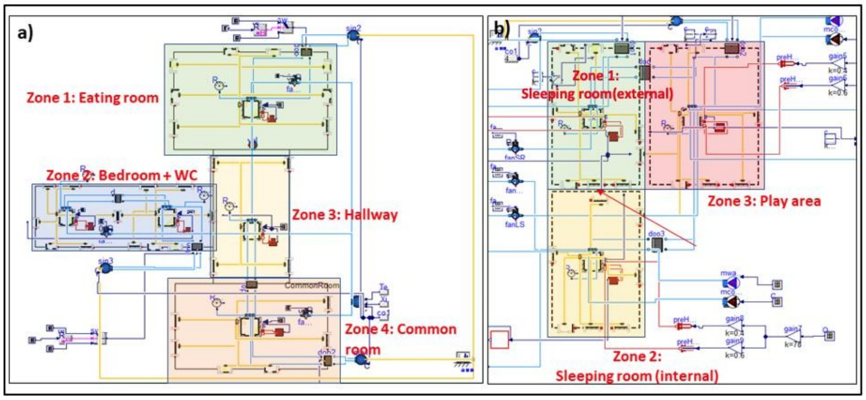

Figure 3. Modelica models of a) PCC and b) CCC sectors

RESULTS

Psychological care homes (PCC)

Figure 4 represents the simulation results for the old and new PCC buildings for scenarios A, B and C (**Table 2**) for MEV. As expected, older constructions with lower ventilation rates had more IAQ problems than newer constructions and the IAQ in the heating season was worse than in the cooling season due to less frequent and shorter window opening. Thus, recommended window opening behaviour is dependent on the construction year and season type. For a threshold of 1200 ppm in the heating season, common rooms in old PCC would benefit from more frequent window opening according to **scenario B** which offers a compromise between IAQ and energy use **(Figure 4b)**. Another option would be more efficient occupancy management (i.e., occupy premises in smaller groups at a time). For a stricter threshold of 900 ppm in the heating season in case of disease circulation and a heightened contamination risk, a less energy efficient **scenario C** is required despite it causing a 30% increase in energy use. The difference in heating energy usage between the old and new facilities was due to a higher heating setpoint active in the new PCC facilities.

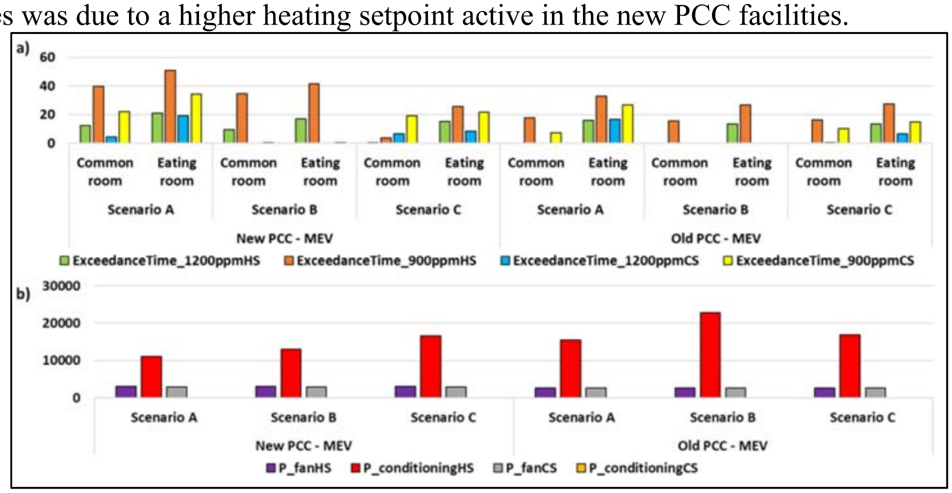

Figure 4. a) Exceedance time of CO2-concentration [% occupied time], b) Energy usage [kWh] in the PCC sector. Results are shown for heating season (HS) and cooling season (CS)

Child day care centres (CCC)

Figure 5 shows the simulation results for the old CCC without mechanical ventilation and the new CCC with a ventilation system type C for window opening scenarios S1, S2, S3 and S4 (**Table 2**). In the case of the old CCC, three different window opening areas (Mourkos et al., 2020) are tested, i.e., 1m² (WO1), 2m² (WO2), 4m² (WO4). In the old CCC, windows must be frequently opened to maintain an acceptable IAQ. Windows with an opening area of 2m² must be opened a full day during heating season in order to avoid an exceedance in CO_2-concentration of 1200 and 900ppm. Due to unfavourable wind conditions during cooling season, a larger window opening area of 4m² is necessary to minimize the exceedance of CO_2-concentrations. **Figure 5b** shows a high increase in heating energy usage for scenario 4 in comparison to scenario 3 (+ 162%), therefore, lowering the allowed occupancy in the room would be a more suitable solution. No additional window opening is necessary in the new CCC when CO_2-concentrations must be below 1200ppm. In case a threshold of 900ppm is applied, windows must be opened 1hour in the morning and during activities during heating season. During cooling season, the windows should be opened a full day to remain below the 900ppm threshold.

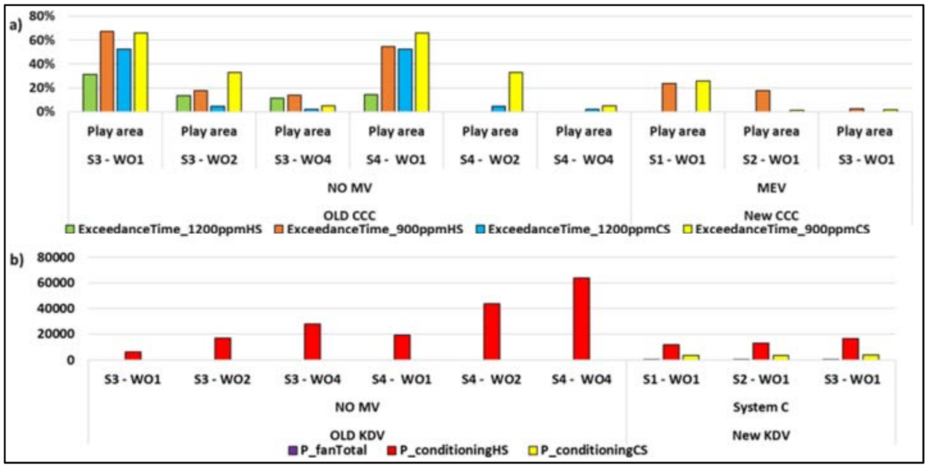

Figure 5. a) Exceedance time of CO2-concentration [% occupied time], b) Energy usage [kWh] in the CCC sector. Results are shown for heating season (HS) and cooling season (CS)

CONCLUSIONS

Table 3 summarises the resulting guidelines per facility (i.e., PCC or CCC), season (i.e., heating or cooling season) and required IAQ threshold (i.e., 900 or 1200ppm). In case the characteristics of a care facility differ from the assumed space properties and occupancy profile, it is advised to verify the suitability the guidelines with CO_2 measurements. The ventilation guidelines for CCC facilities will be checked with the results of field measurement campaigns performed by VITO in the future.

Table 3. Practical ventilation guidelines

a) PCC: Old facility – Ventilation type C			
1200 ppm		**900 ppm**	
Heating season	**Cooling season**	**Heating season**	**Cooling season**
The current ventilation flow rate is insufficient. Open windows after activities in the space or decrease the allowed occupancy in the room.	The current ventilation flow rate is insufficient. Keep windows open all day and night. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.	The current ventilation flow rate is insufficient. Opening windows is not sufficient. Decrease the allowed occupancy and/or occupancy duration in the room.	The current ventilation flow rate is insufficient. Keep windows open all day and night. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.
b) PCC: New facility – Ventilation type C			
1200 ppm		**900 ppm**	
Heating season	**Cooling season**	**Heating season**	**Cooling season**

The current ventilation flow rate is sufficient. No additional measures are necessary.	The current ventilation flow rate is sufficient. No additional measures are necessary.	The current ventilation flow rate is insufficient. Opening windows is not sufficient. Decrease the allowed occupancy and/or occupancy duration in the room.	The current ventilation flow rate is insufficient. Keep windows open all day and night. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.
c) CCC: Old facility – No mechanical ventilation			
1200 ppm		**900 ppm**	
Heating season	**Cooling season**	**Heating season**	**Cooling season**
The current ventilation flow rate is insufficient. Open windows with an opening area of 2m² the whole day or decrease the allowed occupancy in the room.	The current ventilation flow rate is insufficient. Open windows with an opening area of 2m² the whole day. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.	The current ventilation flow rate is insufficient. Open windows with an opening area of 2m² the whole day or decrease the allowed occupancy in the room.	The current ventilation flow rate is insufficient. Open windows with an opening area of 4m² the whole day. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.
d) CCC: New facility – Ventilation type C			
1200 ppm		**900 ppm**	
Heating season	**Cooling season**	**Heating season**	**Cooling season**
The current ventilation flow rate is sufficient. No additional measures are necessary.	The current ventilation flow rate is sufficient. No additional measures are necessary.	The current ventilation flow rate is insufficient. Open windows with an opening area of 1m² 1hour in the morning and during activities.	The current ventilation flow rate is insufficient. Open windows with an opening area of 2m² during activities. In case of a heat wave, it is advised to keep windows closed and to decrease the allowed occupancy in the room.

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