# Performance comparison of different ventilation strategies in elderly care homes in Belgium

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#### ABSTRACT

Elderly people residing in nursing homes spend a vast majority of their times indoors and often in common recreation areas, to allow for socialization and interaction. Elderly people are a vulnerable age group. Hence, it is essential to provide them with good breathable air quality during these common activities and reduce cross contamination through ventilation. Prolonged exposures of elderly to contaminants may adversely affect their health, quality of life and increase medical expenditures due to frequent hospitalizations. In Belgian elderly care homes, 3 typical ventilation strategies are commonly found (natural ventilation, extract and balanced mechanical ventilation). The aim of this work is to determine the windows opening strategies and duration for the ventilation strategies to deliver good indoor air quality. The impact of window opening on thermal comfort and energy use during heating and cooling season will be assessed. To conduct this work, models of the common room and equipped systems were developed in Modelica. The performance was assessed using two indicators: ppm.hours (for  $CO_2$ ), degree.hours, and days where RH(%) went outside the acceptable [30-70]% range.

#### **KEYWORDS**

Ventilation, elderly care homes, indoor air quality, energy use, occupant behaviour

## **1 INTRODUCTION**

Indoor air pollution is a pressing public health issues given the fact that building policies are dictating airtight envelopes which gives rise to build-up of indoor contaminants. Thus, indoor concentrations of several contaminants can be significantly higher than those outdoors (Bruce et al., 2000). In modern day society, people spend 80-90% of their day in indoor environments. Notably, retired elderly people belonging to the vulnerable populations, residing in elderly care homes are likely to spend even more time indoors (Almeida-Silva et al., 2014). Thus, indoor air quality (IAQ) is of special concern in these types of spaces.

Many field studies in elderly care homes conducted in the EU have already shown poor IAQ and prolonged exposure to high levels of indoor pollution due to inadequate ventilation and its correlation to decreased health of elderly residents (Almeida-Silva et al., 2014; Annesi-Maesano et al., 2013). Exposure to indoor pollution is likely to become acute in the face of disruptive events or shocks such as pandemics. The COVID-19 pandemic has proven to be detrimental for elderly people's livelihoods. For vulnerable populations, acute exposure to high levels of contaminants or exposure to contagious pollutants can threaten their wellbeing and should be prevented with adequate ventilation.

During the pandemic, facility managers and health care workers operating the elderly care homes and taking care of the residents were advised to maximize window opening to dilute the concentration of contaminants, especially in common room areas. However, this can risk in increasing energy use and compromising thermal comfort without bringing much added benefits to IAQ.

The aim of this work is to determine the windows opening strategies and duration for the ventilation strategies to deliver good indoor air quality throughout the year. The impact of window opening on thermal comfort and energy use during heating and cooling season will be

assessed. Different building orientation were also considered. To conduct this work, models of the common room and equipped systems were developed in Modelica. The performance was assessed using two indicators: ppm.hours (for CO<sub>2</sub>), degree.hours, and days where RH(%) went outside the acceptable [30-70]% range.

# 2 METHODOLOGY

# 2.1 Space and systems' description

Elderly care homes in Belgium are often multi-floor mid-sized buildings consisting of residential rooms, common rooms, utility rooms and offices for staff. Common rooms – of particular interest in this study, are recreational areas, where elderly residents take their meals (breakfast, lunch, and dinner), socialize, and/or conduct recreational activities (e.g., watching television). A typical common room (13.3 m × 6.8 m × 2.7 m) located in an elderly care home in the city of Gent, Belgium was considered in this work (**Figure 1a**). Based on the information provided by the Agency of care and health in Belgium (Home | Zorg En Gezondheid, n.d.), this room was occupied by a maximum of 15 people daily, corresponding to a maximum occupant density of 0.17 persons/m<sup>2</sup>. The group of 15 residents of the elderly care home frequented the common room at least three times a day for meals. On average, there was always 5 people occupying the room. Three days of the week (Monday, Wednesday and Friday), group activities were conducted in the afternoon. The weekly occupancy schedule can be seen in **Figure 1b**.

The envelope of the common room consists of an external wall located on the southwest (SW) façade in the direction of prevailing winds (U-value =  $0.21 \text{ W/m}^2$ .K). The external wall had two double-glazed windows with a window to wall ratio of 0.48 and a U-value of 1.1 W/m<sup>2</sup>.K. The opposite internal wall connected to the corridor and the rest of the internal walls connected to utility and laundry rooms. The rest of the boundaries (internal walls, floor, ceiling) were considered as 'adiabatic' to represent a zone within a larger floor plan with other floors above and below. The envelope was air-tight with a rate of 0.3 h<sup>-1</sup> (n-value).





In elderly care homes in Belgium, common rooms are usually ventilated by three types of ventilation systems depending on the type of construction:

1. **Natural ventilation** (found in old constructions): The windows served as inlet and a sanitary block located on the ceiling level in the hallway acting as a natural exhaust. Motorized windows opened automatically during occupied hours starting at 6:30 a.m. until 10:30 p.m. 4 different

opening strategies will be tested and are illustrated in **Figure 2**. This system will be denoted as **System A** for the remainder of this work.

2. System C (found in more recent constructions): The polluted room air was exhausted from the room to the outdoors from a mechanical extract (local ceiling fan). For system C, the ceiling fan operated from 6:30 a.m. – 10:30 p.m. at a flow rate of 24 m<sup>3</sup>/h per person (IDA class 3) (Standard EN 13779), which is what is currently applied in elderly care homes in Belgium. The operation time of the fan was 16 hours. This might result in an insufficient ventilation capacity in current constructions which is why assistive window opening according to the strategies of Figure 2 were applied. The effect of the different window opening strategies on energy costs will be reported and compared to an increase in mechanical ventilation capacity.

3. System D (found in more recent constructions): The polluted room air was exhausted from the room to the outdoors from a ceiling fan and replaced by outdoor clean air supplied from the ceiling level as well. For system D, the ceiling fan operated from 6:30 a.m. - 10:30 p.m. at a flow rate of 24 m<sup>3</sup>/h per person (IDA class 3) (Standard EN 13779), which is what is currently applied in elderly care homes in Belgium. The operation time of the fans was 16 hours. This might result in an insufficient ventilation capacity in current constructions which is why assistive window opening according to the strategies of **Figure 2** were applied. The effect of window opening on energy costs will be reported and compared to an increase in mechanical ventilation capacity.

The common room was equipped with radiators used to maintain the room temperature in the winter at an average of 22°C during occupied hours. During the cooling season, an active cooler was available and operated only if temperatures in the room exceed 26°C.



# Figure 2: Window opening patterns

## 2.2 Pollution sources, IAQ and thermal comfort assessment

The pollution sources considered here were first  $CO_2$  from outdoors and indoor generation due to occupancy respiration. The outdoor concentration was considered equal to 400 ppm and the occupant generation rate equal to 0.0037 l/s per person (Persily & de Jonge, 2017). For  $CO_2$ , the threshold in elderly care homes in Belgium was to be maintained at 1200 ppm, but that value was lowered to 900 ppm during the COVID-19 pandemic. In this work, an average threshold of 1000 ppm was assumed. Water vapor was also considered and was generated by occupancy (latent heat generation, 45 W under sedentary activities) and infiltrated from outdoors.

To compare the ventilation systems and the effect of the occupants' window opening patterns, the *ppm.hours* exceeding 1000 ppm were calculated for CO<sub>2</sub> during the occupied periods only. Thermal comfort was also assessed through the degree.hours of exceedance. The temperature threshold during the heating season (October through April) was equal to 22°C and 26°C during the cooling season (May through September). The amount of time that the RH(%) was spend outside the [30-70]% was also assessed a well as the cooling and heating energy usage.

# 2.3 Modelica models

To accurately compute the temporal variation of CO<sub>2</sub> concentrations in the common rooms, an appropriate model was needed. A simulation tool that can model the building dynamics, HVAC systems, their control, and varying events with different time scales, was needed. Hence, the Modelica language in the Dymola environment was selected (Dymola -Dassault Systèmes®) as it is an open-source, equation-based modeling language with an objectoriented structure. Modelica gives access to specific libraries that contain validated sub-models of the building envelope, systems, and their control. The "*Integrated District Energy Assessment by Simulation*" (*IDEAS*) library will be used in this work (Jorissen et al., 2018). Despite the use of validated sub-components, the full model still needs to be validated against measurement data. **Figure 3** shows the Modelica model of the common room as seen in Dymola for ventilation system D.

The model takes as input the TMY weather files and outdoor pollutants' concentrations using the simulation info manager as seen in **Figure 3**. The weather data collected from a weather station in Gent for the year 2022 was used (al Assaad Douaa et al., 2022). In the zone model, the envelope characteristics, occupancy schedule, sensible and latent heat generations from occupants (75 W and 45 W respectively during sedentary activities) were defined as well as the pollutants' generation rates. Sensible heat generation due to lights was defined in Modelica through the lux value (500 lux) in the zone model. The lights were LED that turned on during occupancy hours. Simulations were conducted for 1 day of the week (Monday) for no shock or base case scenario and shock scenarios.

Figure 3: Modelica model of the considered space with its heating, cooling, and ventilation system (illustrated is system D)



#### **3 RESULTS AND DISCUSSION**

The results section will first present an analysis of the indoor environmental quality in the elderly care home common room (IAQ, thermal comfort) and energy use while comparing the different systems during heating and cooling seasons. The results section will then conclude on the optimal window opening strategies for the different systems.

## 3.1 IAQ in the common room area

**Figure 4** illustrates the ppm.hours of  $CO_2$  exceeding the 1000 ppm threshold during heating and cooling seasons for systems A (natural ventilation), system C (mechanical extract, ACH = 1.5) and system D (balanced mechanical ventilation, ACH = 1.5), for 4 window opening patterns and for 4 different building orientations (window side facing either South, North, West and East).

According to **Figure 4**, the IAQ violations for all systems, for all building orientations and all window opening patterns were higher during the cooling season rather than the heating season due to unfavorable wind directions and speeds during the latter.

During the heating season, system D had the lowest IAQ violations followed by system A and finally system C. This applied to all four building orientations and for all the window opening patterns. System D had the best performance given the fact that it additionally supplies clean outdoor air unlike system C which only extracts contaminated air and relies on fresh air infiltration from the building envelope and trickle vents. Note that the infiltration was not that efficient given the airtightness of the building envelope. System A outperformed System C. This can be due to large pressure gradients created by opening of windows and the sanitary block in the hallway driving in considerable amount of fresh air to ventilate the room unlike system C, that relies on a mechanical extract.

During the cooling season, system D remained the highest performing for all building orientations and all window opening patterns. System C only outperformed system A for south oriented windows while system A outperformed system C. For all the different systems, when the duration of the window opening decreased, going from Pattern 1 to Pattern 4, the IAQ violations increased due to lower air change rates from natural ventilation. This was more pronounced in the heating season rather than the cooling season during which the wind directions and speeds were less favorable.



Figure 4: CO<sub>2</sub> ppm.hours for systems A, C and D for different window opening patterns during the heating and cooling seasons.

**Figure 5** illustrates the number of days where RH(%) exceed the. [30-70]% range during the heating and cooling seasons for systems A (natural ventilation), system C (mechanical extract, ACH = 1.5) and system D (balanced mechanical ventilation, ACH = 1.5), for 4 window opening patterns and for 4 different building orientations (window side facing either South, North, West and East). According to **Figure 5**, the number of days violating the RH(%) acceptable range were higher during the winter seasons than during the summer season. This was due to drier indoor conditions in winter due to heating and the longer duration of the heating season as compared to the cooling season. Additionally, with decreasing duration of window opening, the violations decreased during the cooling season. During the heating season and cooling seasons, similarly system D had the lowest violations followed by system A and closely by system C.



Figure 5: #days RH(%) exceeded [30-70]% range for systems A, C and D for different window opening patterns during the heating and cooling seasons.

## 3.2 Thermal comfort and energy use

**Figure 6** illustrates the degree hours exceeding the 22°C threshold during heating season and 26°C threshold during the cooling season for systems A (natural ventilation), system C (mechanical extract, ACH = 1.5) and system D (balanced mechanical ventilation, ACH = 1.5), for 4 window opening patterns and for 4 different building orientations (window side facing either South, North, West and East). **Figure 7** illustrates the corresponding heating and cooling power consumptions.

According to **Figure 6**, the violations during the heating season were much larger than those during the cooling season where the violations were rather negligible. In fact, during the cooling season, due to the moderate climate, the outdoor temperatures were not that high. Thus, no overheating occurred and the 26°C threshold was not violated. It follows that the power consumption during the cooling season was lower than during the heating season (**Figure 7**). Note that during the cooling season, the power consumption was comparable between the different systems. During the heating season, violations decreased with decreasing duration of window opening patterns given the lower amount of infiltrating outdoor air that needs to be heated. The same was observed during the cooling season but at lower rates.

Comparing the different systems, system C had the lowest violations due the low amount of infiltration as previously stated, followed by system D and finally A. It follows that the highest power consumption was for system A, followed by system D and closely by system C. Finally, between the building orientation, the south oriented windows had the lower power consumption demand given the high solar radiation on the south facades and thus a reduced amount of heating needed.



Figure 6: Degree.hours for systems A, C and D for different window opening patterns during the heating and cooling seasons.

Figure 7: Heating and cooling power consumptions (KWh) for systems A, C and D for different window opening patterns during the heating and cooling seasons.



# 3.3 Window opening patterns

To determine the window opening patterns for each system, the analysis will rely on the ppm.hours and energy use. This is since the violations of degree.hours were not as high as the ppm.hours. Moreover, the discrepancy between the degree.hours of the different scenarios (systems, window patterns) were not as pronounced as the ppm.hours (**Figure 4-7**). In Belgium, there is no threshold values of acceptable yearly *ppm.hours*. A value of 30,000 ppm.hours was adopted in the Netherlands and was considered in this work. This was divided proportionally between the heating and cooling seasons (20,000 and 10,000 respectively).

For system A, during the heating season, windows can be kept open under Pattern 4 for IAQ benefits given the lower power consumption. During the cooling season, this can be Pattern 1 despite the higher power consumption due to the significant IAQ violations of Patterns 2 to 4. This applies for all orientations.

For system C, during the heating season, for south oriented windows, an optimal case would be to replace the current fans with a fan that can supply an ACH of 2. For this scenario, the windows can be closed during the operation without having any IAQ violations and with the benefit of lower power consumption compared to an ACH of 1.5. However, if this is not possible, an ACH of 1.5 with a window opening Pattern 3 would be the better option as a compromise between IAQ and energy. The same applies for north and west orientations. However, for the East orientation, due to the significantly higher ppm.hours, it would be better to open the windows at Pattern 2 for slightly higher IAQ benefits. During the cooling season, for all orientations, it is better to resize the fan at ACH of 2 while closing windows as well. However, if this is not possible, an ACH of 1.5 with a window opening Pattern 1 would be the better option since energy use during the cooling season was not that high. Thus, it is better to take advantage of the IAQ benefits.

For system D, during the heating season, the windows can be opened even less (system D has higher IAQ performance). For all window orientations, an ACH of 1.5 with Pattern 0 can be suitable. During the cooling season, and for all window orientations, an ACH of 1.5 with Pattern 0 was also acceptable.

#### 4 CONCLUSION

In this work, the possible window opening strategies in an elderly care home were studied for different existing pre-sized mechanical ventilation systems and natural ventilation strategies. The choice of window opening patterns were selected based on a compromise between IAQ and energy use between heating and cooling seasons since thermal comfort violations were not

as significant. Different building orientations were also considered. The obtained results are summarized in the table below:

System type	Window opening strategy		
Natural ventilation	Heating season: Pattern 4 (Open during		
	afternoon): all orientations		
	Cooling season: Pattern 1 (Open all day		
	during occupied periods): all orientations		
Mechanical extract $(ACH = 1.5)$	Heating season: Pattern 3 (open during		
	morning and evening): south, west, north		
	Pattern 2 (Open during high occupancy		
	periods): east		
	Cooling season: Pattern 1, all orientations		
Balanced mechanical ventilation (ACH =	Heating season: Windows can be kept		
1.5)	closed (all orientations)		
	Cooling season: Windows can be kept		
	closed (all orientations)		

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Table I	Window	opening	strategies
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