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Analysis of Potential Impacts of Policy Options for Inspections of Stand-alone Ventilation Systems in EU Dwellings

Arnold Janssens, Phd
Member ASHRAE

Yanaika Decorte

Francois Durier
Member ASHRAE

Peter Wouters, Phd
Member ASHRAE

ABSTRACT

Various field studies have shown that in a vast majority of European countries the quality of installed residential ventilation systems is poor, with a large proportion of systems having significantly lower installed flow rates than the required values, or having poor energy performance due to flaws in design, installation or operation. This paper analyses the potential impact of different policy options for an EU-level approach for inspection of stand-alone ventilation systems in residential buildings until 2050. The analysis accounts for different scenarios based on the evolution of the EU dwelling stock, the evolution of the market share of ventilation systems in buildings, and the impact of policy options for inspection on the ventilation related energy use and indoor air quality in dwellings equipped with various types of ventilation systems. This analysis is part of a technical study contracted by the Directorate-General for Energy of the European Commission to a consortium formed by INIVE and BPIE, whose aim was to provide technical support on the possibilities and timeline for introducing inspection of stand-alone ventilation systems in buildings, linked to Article 19a of Directive 2018/844, which requires that the Commission must carry out a feasibility study on this topic. The paper discusses the methodology and results of the impact analysis calculations. The calculations of ventilation related energy indicators and carbon emissions are based on the principles of the ecodesign SEC-calculation method (Directive 2009/125/EC). The IAQ-indicator is based on the assessment of a generic pollutant dose taking account of the effective flow rates and exposure times in the different types of ventilation systems. The results show that inspection options contribute to a smaller or larger extent to a better indoor air quality, at the same time increasing the ventilation related energy use. It is not evident to rank the various policy options in terms of preferences: they could be implemented consecutively, by looking at societal support in case of a mandatory implementation.

INTRODUCTION

Article 19a of the amended Energy Performance of Buildings Directive 2010/31/EU (EPBD), introduced by Directive 2018/844/EU (EC 2018), required the European Commission to conduct a feasibility study to identify the need, possibilities and timeline for introducing EU provisions related to the inspection of stand-alone ventilation systems eg the development or improvement of technical standards, guidelines and practices, or the possible extension of the mandatory regular inspection requirements of the EPBD to ventilation systems. In this study, stand-alone ventilation systems are defined as ventilation systems whose sole function is to ventilate a building.

The feasibility study consisted of 3 tasks: (1) review of regulations, guidelines and standards on the inspection of stand-alone ventilation systems, (2) analysis of the relevance, feasibility and possible scope of measures at EU-level for the

Arnold Janssens is a professor in the Research Group Building Physics, Faculty of Engineering and Architecture, Ghent University, Belgium. **Yanaika Decorte** is a Phd-student in the same research group. **François Durier** is Director of Development and Partnerships at CETIAT, France. **Peter Wouters** is General Advisor at BBRI and Manager of INIVE EEIG, Belgium.

inspection of stand-alone ventilation systems, and (3) selection of policy options for inspections of stand-alone ventilation systems and analysis of related potential impacts. This paper covers the third task, and describes the modeling approach developed to assess the impacts of policy options, for different ventilation systems and their stock, and taking into account their different defects and the ability of the policy option to correct these defects. For this purpose the model has been implemented into an Excel tool to perform calculations to analyse the impacts of policy options on ventilation related electrical and primary energy use and indoor air quality (IAQ) towards 2050.

The application of the impact analysis calculation is illustrated for six different policy options of inspections. They cover legislative and non-legislative measures, including three options with mandatory inspection, one option with voluntary indoor air parameters measurements and two options outside of inspection, namely awareness raising of stakeholders and training of installers. Since the data about the stock and sales of ventilation systems from a previous part of the study showed that 93% of stand-alone ventilation systems are installed in residential buildings, the analysis focuses on residential buildings. More details of the study are available in the report by Durier et al. (2019a).

METHODOLOGY OF IMPACT ANALYSIS

Overall approach

The methodology consists of three steps, which are performed for 5 European climate regions, and for the EU-28. In a first step the performances of 10 different types of residential ventilation systems are calculated, considering the impact of inspection policy options on various parameters influencing the energy use and IAQ, such as the quality of design and installation, the control of systems, the specific fan power, etc. The calculations of ventilation related energy indicators are based on the ecodesign SEC-calculation method (EC 2014). Energy performances are expressed as a specific value per m² of floor area, and quantify the average performance of dwellings with a specific type of ventilation system. The IAQ-indicator is based on the assessment of a generic pollutant dose taking account of the effective flow rates and exposure times of the different types of ventilation systems.

In a second step the distribution of different types of ventilation systems in the existing dwelling stock is estimated, and the evolution of the market share of ventilation systems in future new and retrofitted dwellings towards 2050. The estimation is based on the analysis of the stock of ventilation systems in EU Buildings (Durier and Leprince 2019) and on the building stock evolution derived from the ‘Agreed EPBD Amendments scenario’ used in the EU commissioned technical study for the development of a smart readiness indicator for buildings (Verbeke et al. 2020). The impact of inspection policy options on the evolution of the market share of ventilation systems is also considered, by assuming that more new ventilation systems are installed in comparison with a baseline option with no actions.

In the third step the specific performance indicators calculated in step 1 are extrapolated to the total building stock by combining the specific performance indicators with the building stock data and the data about the market share of ventilation systems, estimated in step 2. As a result the impact of policy options may be compared for the energy use as a result of the ventilation of the dwelling stock, and for the average exposure to pollutants over the dwelling stock. Given the uncertainties and the many parameters involved in the ventilation system performance calculation, in the estimated evolution of the ventilation stock and in the estimated distribution of ventilation system types over the dwelling stock, the outcome of the analysis should be treated with care. In the following paragraphs the three steps of the analysis are explained in more detail.

Calculation of performance indicators

Type of ventilation systems. An important element in the impact analysis study is the type of ventilation systems under consideration, because the impact of quality related measures, assessed during inspections, can vary widely as function of the type of ventilation system. The calculation tool takes 10 types of ventilation systems into account. Categories are listed in Annex 1. The main categories are based on the analysis of the stock of ventilation systems in EU Buildings (Durier and Leprince 2019), and vary from systems with natural supply and exhaust to central bidirectional mechanical systems, with subcategories based on the types of controls, ranging from manual control to demand controlled and smart control. Terminology used is from eco-design (EC 2014).

Specific primary energy use as a result of ventilation. This is the sum of the fan energy use (in case of mechanical ventilation) and the heating energy use to cover ventilation heat loss. For the latter estimated ventilation rates are combined with climate data and a simplified energy model to estimate the heating demand and the primary energy use. The calculation method is based on the eco-design SEC calculation (specific energy consumption, EC 2014), with Equation 1 giving the primary fan energy use $P_{f,p}$ (Wh/(m²year)), and Equation 2 the primary heating energy use $Q_{h,p}$ (Wh/(m²year)):

$$P_{f,p} = t_a . pef . q_{net} . f_{qual} . f_{ctr}^{x} . f_{use} . SFP \tag{1}$$

With t_a the annual operating hours (8760 h/year), pef the primary energy factor for electrical power generation and distribution (taken equal to 2.5), q_{net} the net ventilation rate demand per heated floor area (m³/(m².h)), f_{qual} the mean quality factor of design and installation, f_{ctr} the mean ventilation control factor, x an exponent depending on motor and drive characteristics, f_{use} the mean user impact factor, and SFP the specific fan power (W/(m³/h)).

$$Q_{h,p} = t_h . \Delta T_h . \eta_h^{-1} . c_{air} . \left(q_{net} . f_{qual} . f_{ctr} . f_{use} . (1 - \eta_t) + n_{50} . H . 0.04 \right) \tag{2}$$

With t_h the heating season hours (h), ΔT_h the average difference between indoor and outdoor temperature over a heating season considering solar and internal heat gains (K), η_h the average space heating efficiency, c_{air} the specific heat capacity of air (J/(kgK)), η_t the average thermal efficiency of a heat recovery system, n_{50} the average air change rate due to leakage at a pressure difference of 50Pa (h^{-1}), H the average floor height (m), 0.04 a scaling factor to scale the air leakage rate at 50Pa to pressure differences under normal climatic conditions. The product $t_h.\Delta T_h$ is climate zone dependent, and may be derived from degree-day data.

Building air tightness is taken into account, because the analysis also considers buildings without ventilation system, where the indoor air quality and the related heat loss depends on the air leakage rate through the building envelope. The net ventilation rate demand q_{net} gives the total design flow rate of fresh air to be delivered by the ventilation system per heated floor area of the dwelling. For natural and unidirectional ventilations systems it is assumed equal to 1.3 m³/h/m² (EC 2014), while for bidirectional systems it is 2 m³/h/m². The quality factor f_{qual} expresses to what extent the air flow rate delivered by the installed system meets the required nominal air flow rate, prescribed in standards or legislation. The factor is expressed as a percentage of the required nominal air flow rate, and is based on literature on quality and compliance of ventilation systems on the market (Maivel et al. 2015, Janssens et al. 2014, SEAI 2019), showing quality factors to vary between 33% and 150%. The control factor f_{ctr} expresses the ratio between the mean air flow rate achieved by the system, considering control actions based on user interaction or sensor information, and the maximum air flow rate deliverable by the installed system. It is assumed that it has an impact on the energy use, but not on the indoor air quality, since it is assumed that the air flow rates are reduced by the controls only at times of reduced ventilation needs. The control factor is assumed to vary between 60% and 100%, based on performance figures of systems on the market, and on the range of control factors defined in the SEC calculation (EC 2014). The user impact factor f_{use} expresses the ratio between the mean air flow rate achieved by the system (considering inappropriate user actions) and the maximum air flow rate deliverable by the installed system. This factor takes account of users reducing air flow rates due to quality issues as acoustics or draught. It has an impact on the energy use and on the indoor air quality, since it is assumed that the air flow rates may be reduced by the user also at times of increased ventilation needs. The user impact factor is assumed to vary between 40% and 100% (Janssens et al. 2014). For all these calculation variables, a distribution is estimated for the whole market of each type of ventilation system.

IAQ-indicator. The IAQ-indicator, or exposure indicator is defined as the ratio between the total pollutant dose and the exposure dose of a system continuously delivering the net ventilation rate demand with reference value 1.3 m³/(h.m²) (Eq. 3). In case of poor IAQ the exposure indicator has a value larger than 1, in case of improved IAQ it has a value smaller than 1. Since the influence of air infiltration through leakages is taken into account, the value of the exposure indicator may be smaller than 1 also in systems which deliver a smaller flow rate than the net ventilation rate demand.

$$IAQ\ indicator = \frac{\sum \frac{p_j}{q_j}}{1/q_{net}} \tag{3}$$

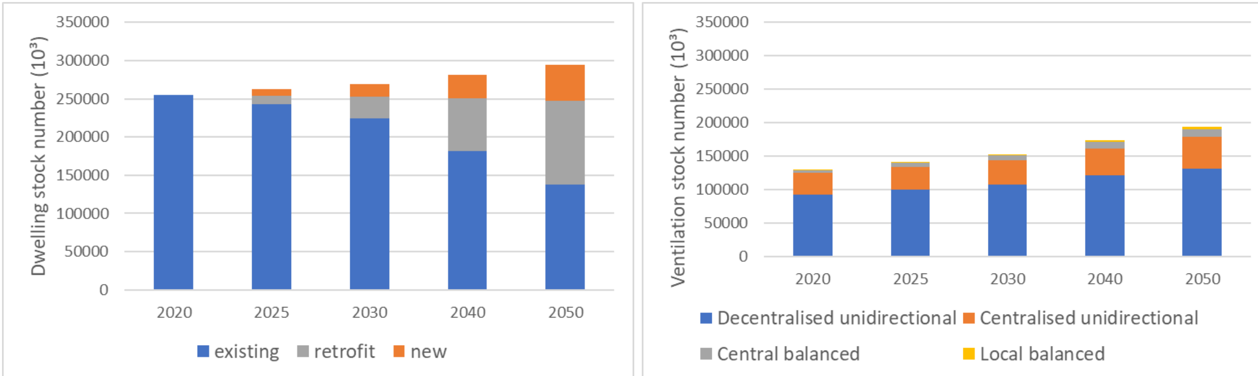

Figure 1 (left) EU Residential stock evolution total number of dwellings. (right) EU evolution total number of ventilation units.

$$q_j = q_{net} \cdot f_{qual} \cdot f_{use} \cdot f_{clim} + q_{inf} \quad (4)$$

With q_j the available flow rate of a specific ventilation system for a specific combination j of flow rate adjustment factors (Eq. 4), and p_j the probability of occurrence of this combination, considering the distribution of each factor. The climate influence factor f_{clim} takes account of the fact that flow rates are not constant over time.

Market share of ventilation systems

Building stock data were obtained through the EU Building Stock Observatory of the European Commission (EC n.d.), and combined with future evolution rate figures for new built, demolition and retrofit from the 'Agreed Amendements scenario' (Verbeke et al. 2020), wich forecasts increased renovation rates after 2026. As a result, the evolution of the number of dwellings and their floor area was derived for Europe and for five predefined climate regions at five moments in time (Figure 1, left). The evolution of the market share of ventilation systems (Figure 1, right), is based on the analysis of the stock of ventilation systems in EU Buildings from the consolidation of existing data by Durier and Leprince (2019). The share of the subcategories (manual, DCV, smart) is estimated starting from the share of main categories. The market share is further refined by comparing the stock of ventilation systems to the dwelling stock evolution. This way the number of dwellings equipped with a specific type of ventilation system may be estimated. Since the total increase of new and retrofitted houses according to the 'agreed amendments pathway' is larger than the increase of ventilation units (Figure 1), the difference between both gives an indication of the number of new and retrofitted houses without ventilation system, for instance because the installation of a ventilation system is not mandatory in every country, or of the number of houses with natural ventilation systems. For the latter, the market share of natural ventilation systems is based on Händel (2010).

Figure 2 shows the result of the combination of these data. The estimates show a gradual evolution of the market share of ventilation systems towards more mechanical and smart systems. A large number of additional assumptions had to be made in the conversion of the ventilation stock to the dwelling stock, eg about the number of decentralized units per dwelling, the number of dwellings served by a central unit, the share and future evolution of DCV and smart systems. The increased renovation rate in the dwelling stock evolution after 2026 is taken into account by assuming that the ventilation stock evolution increases at the same rate as the dwelling stock evolution. The increase is depending on the climate region but is in the order of 30%. To give a good understanding of the separate impact of policy options related to inspections, it is assumed that no change in other ventilation regulations between now and 2050 will occur. This means that there is little to no increase in ventilation systems in countries which today have no ventilation requirements for new and renovated dwellings (eg Germany, Greece). This results in approximately 50% of new and retrofitted EU-dwellings not being equipped with new ventilation systems.

Assumptions for an option with no action

The impact of policy options for inspection is compared to a baseline scenario with no specific policy actions at a European level (also referred to as 'no policy options'). This scenario considers the fact that in a vast majority of European countries the quality of installed ventilation systems is very poor. The main factors taken into account in the calculation of the performances of different ventilation systems are the following:

- A large proportion of systems (20%-55% depending on system type) have lower flow rates than the required values;
- In a large proportion of systems (50%-75% depending on system type) users operate the systems at lower flow rates than the nominal values, e.g. because of noise or draft problems;
- A large proportion of mechanical ventilation systems (25%-70% depending on system type) have a higher specific fan power than the default values defined in ventilation standards (500-750 W/(m³/s) per fan);
- A large proportion (50%) of balanced mechanical systems with heat recovery have imbalanced supply and extract air flows or malfunctioning devices, decreasing the heat recovery performance.

Figure 3 shows the evolution of the ventilation related primary energy use of the European dwelling stock, and the evolution of the average exposure to pollutants over the dwelling stock for this baseline scenario. These global indicators are derived by merging the direct indicator (Eq. 1-3) with data on the evolution of the building stock and on the share of the ventilation systems. The calculation method consists of two components. The first component is related to the share of existing ventilation systems, for which the performances are not affected by inspection policy options. The second component applies to the share of newly installed systems in new and retrofitted dwellings, for which the performance depends on the policy options.

As a result of the growth of the dwelling stock and of the expected increase of ventilation systems on the market, the primary energy use as a result of the ventilation of the dwelling stock (fan energy, ventilation and infiltration heat loss) will increase by 18% in between 2020 and 2050, while the average exposure to pollutants will decrease by 10%. For comparison: the EU dwelling stock floor area is estimated to increase by 15% in between 2020 and 2050. The total primary energy use is dominated by the primary heating energy use related to ventilation and infiltration, while the primary fan energy use represents a small fraction (3% in 2020, 6% in 2050) of total primary energy use. A large share of the total primary energy use is the result of infiltration due to air leakages (57% in 2020, 53% in 2050).

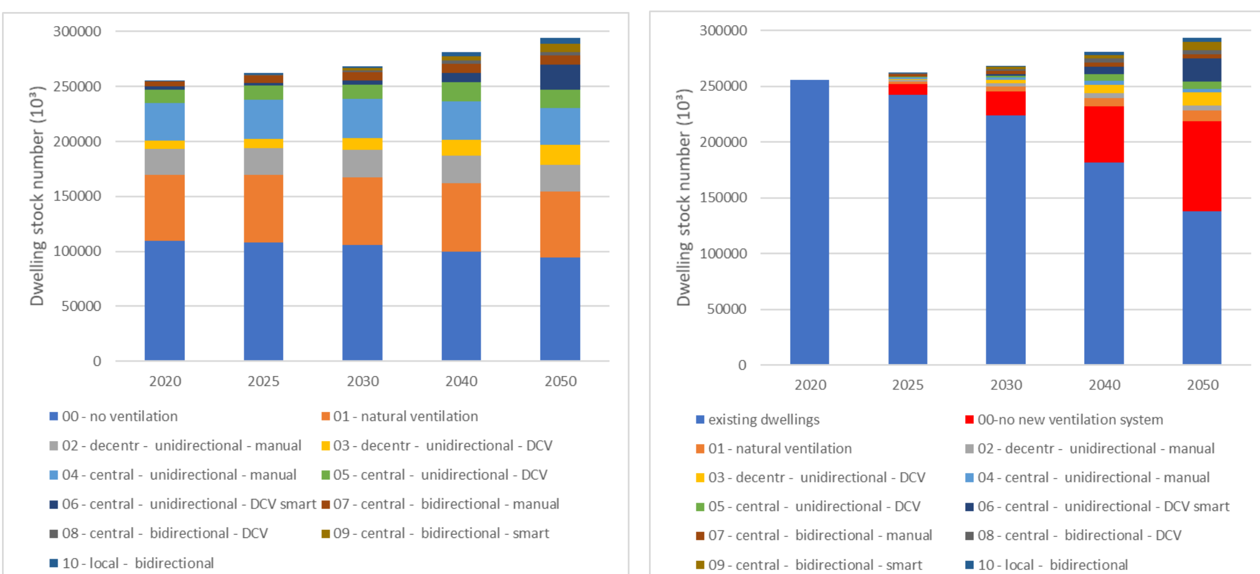

Figure 2 (left) EU evolution of total number of dwellings with a specific ventilation system, (right) EU evolution of the number of future new and retrofitted dwellings with specific ventilation systems, and of existing dwellings where no renovation will occur.

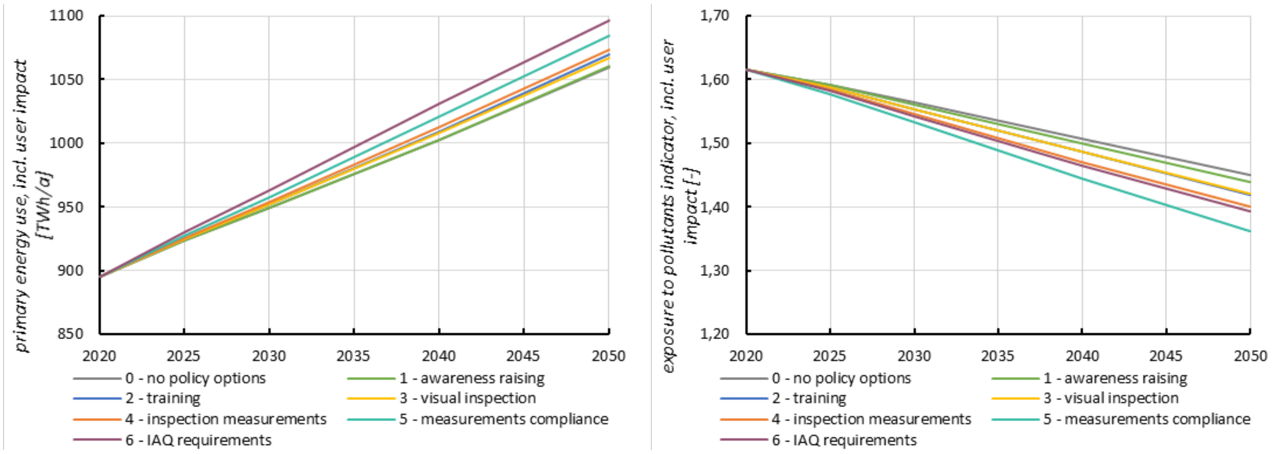

Figure 3 (left) Evolution of the ventilation related primary energy use of the EU dwelling stock, (right) Evolution of the average exposure to pollutants over the EU dwelling stock, for the base line and 6 policy options.

IMPACT ANALYSIS OF INSPECTION POLICY OPTIONS

Selected policy options

In addition to the baseline scenario, the following policy options have been analysed regarding their potential impacts:

1. Better knowledge about the status on the ground in combination with awareness raising of stakeholders.
2. Professionals skills increase through mandatory training programmes of installation companies.
3. Mandatory initial visual inspection of new ventilation systems in buildings after their installation, performed by qualified companies.
4. Mandatory initial inspection of new ventilation systems after their installation, performed by qualified companies, including measurements of air flow rates at room level and fan(s) electrical power input.
5. The same as option 4 with the additional requirement that the ventilation system is made compliant within a certain delay if the inspection shows non-compliance, with follow-up inspection.
6. Requirements for maximum values of an indoor air quality indicator, eg CO_2-concentration in living rooms. Measurement of indoor air quality parameters can be performed or asked by occupants or owners. Corrective actions rely on further initiative of the owners.

It has been chosen to estimate the impact of the different options for new stand-alone ventilation systems installed in new or renovated buildings; this is consistent with the finding that existing regulations and guidelines mainly relate to initial inspection of new systems (Durier et al. 2019b). The policy options may both have an influence on the market share of ventilation systems and on their performance. With respect to the market share, inspections may increase the installation of new ventilation systems in comparison with the baseline scenario, mainly because the policy options might impact the application of ventilation systems in countries where the installation of ventilation systems is not mandatory, or in projects with requirements to install ventilation but where compliance is not checked or enforced. Inspections with measurements may also lead to a faster shift towards smart systems, for instance because in these systems it is easier for installers to perform the required measurements. With respect to system performance, in the impact analysis it is assumed that the policy options have, to a different degree and depending on system type, a positive influence on the quality of design and installation, resulting in more systems achieving required flow rates, less systems operated at significantly lower flow rates than nominal values because of comfort problems experienced by users, more systems achieving specific fan power default values, and less systems with imbalanced or malfunctioning heat recovery system, in comparison with the option with no actions. The estimates of policy options on compliance, market share and performance is based on the scarce literature (Carrié et al. 2015), and on expert judgment. Table 1 gives an overview of the main figures taken into account in the analysis.

Table 1. Estimated mean impact of inspection policy options compared to baseline

Policy option	Increase of new ventilation systems on market	Increase of systems achieving required flow rate	Descrease of systems operated at lower flow rate	Increase of systems achieving SFP default values	Decrease of systems with poor heat recovery
1	5%	0%	0%	0%	0%
2	5%	0-10%	5-10%	10%	5%
3	10%	5-20%	10%	0%	0-5%
4	10%	10-35%	10%	15-20%	5-25%
5	20%	20-55%	10-15%	15-20%	20-35%
6	10%	10-30%	10%	0%	0-5%

Impact analysis findings for the 6 options

Figure 3 gives an overview of the impact of the 6 policy options on the ventilation related primary energy use and on the average exposure to pollutants in the total EU dwelling stock. The impact analysis indicates as an overall trend that the various options result in a better indoor air quality but also in a higher energy consumption. Policy option 5 (inspection with measurements and compliance) results for the total EU dwelling stock in the largest reduction of the average exposure to pollutants in the dwelling stock (-6% by 2050), and the second largest increase of the ventilation related primary energy use (+2% by 2050), compared to the option with no actions. Half of the impact on pollutant exposure and 12% of the impact on primary energy use is related to the assumed 20% increase of newly installed ventilation systems for this option.

The observed overall trend is the consequence of the fact that in a vast majority of European countries the current quality of installed ventilation systems is shown to be poor, and delivered air flow rates are often insufficient. Options 1 to 6 might result in better designed and executed ventilation systems and therefore higher ventilation rates. Without inspections, it is not possible to ensure that all buildings required by regulations to have ventilation systems do indeed have them installed. Options 1 to 6 can reduce the number of buildings without a ventilation system, and result on average in a higher ventilation rate. Furthermore building occupants might not use the system or use it at a lower capacity due to issues of noise, draught, the intention to save energy, etc. Options 1 to 6 should directly or indirectly result in more correctly installed ventilation systems and, if attention is paid to the previously mentioned issues, in a more effective operation of such ventilation systems.

When considering the aggregated results over the EU dwelling stock, the policy options seem to have a marginal impact. However, this is the consequence of the chosen scope of the impact analysis, and of the fact that dwellings equipped with new ventilation systems on which the policy options have effect represent a small share of the total dwelling stock. When analysing the impact of the policy options over the EU dwelling stock with newly installed ventilation systems only, the impact of the options is more pronounced. In this part of the stock, the policy options result in important reductions of the average exposure to pollutants, up to 22% (2025) and 17% (2050) in case of option 5. The ventilation related primary energy use aggregated over all EU dwellings with newly installed ventilation systems, and divided by the total floor area of those dwellings with new systems (specific primary energy use) increases up to 26% for the same option. Because of the shift to systems with DCV and smart controls, the specific primary energy use and the exposure to pollutants is reduced towards 2050 for all options. The impacts of the policy options are also system type dependent: in half of the 10 studied systems, natural ventilation, bidirectional systems with heat recovery, inspection contributes to an improved IAQ with limited or no increase of primary energy use.

CONCLUSIONS

The impact analysis shows as an overall trend that the various considered options contribute to a smaller or larger extent to a better indoor air quality, whereby at the same time increasing the ventilation related energy consumption. These findings are directly related to the assumption that, on average, actual dwelling ventilation is too low for achieving good IAQ and that all of the options should contribute to an increase in air flow rates. It is crucial in the cost-benefit analysis of the introduction of inspection to pay attention to the cost of poor IAQ on health, impact on productivity, and other factors due to a poor IAQ.

In general, the existence of sufficient awareness among citizens and decision makers is crucial to have societal support for the mandatory implementation of inspection schemes. Moreover, awareness campaigns can also be a driver for appropriate ventilation or IAQ requirements in countries which have not yet such type of requirements. A valid alternative for inspection of ventilation systems can be imposing requirements on indoor air quality. This might in practice lead to the voluntary inspection of ventilation systems with the advantage of having effect during the whole lifetime of occupation. The study discussed in this paper was performed before the start of the covid-19 pandemic. Since then, ventilation performance and indoor IAQ monitoring has received a lot of attention in many countries, raising awareness among policy makers and the general public, and creating more suitable conditions for the introduction of ventilation requirements and inspection schemes.

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ANNEX 1: TYPE OF VENTILATION SYSTEMS

0. No ventilation: there are still many buildings without a ventilation system. This is the case for existing buildings, but also for new buildings, in countries where it is not mandatory to install ventilation systems, or even sometimes when there are regulations in place, but which are not respected.
1. Natural supply and Exhaust – manual: fully natural ventilation, which may include air supply grills and extraction grills connected to chimneys. Opening and closing of devices can be possible or not possible, depending on country regulations. In case possible, it is by manual control.
2. Decentralised unidirectional systems – manual: systems consisting of free air supply ventilators, and one or more mechanical exhaust fans in dedicated rooms. Manual opening or closing of ventilators can be possible or not possible, depending on country regulations. Exhaust fans may be manually switched on or off.
3. Decentralised unidirectional systems – DCV: Identical to system 2, but exhaust fans are demand controlled by built-in sensors.
4. Central unidirectional systems – manual: ventilation system with natural supply ventilators and a single central mechanical exhaust fan. Manual opening or closing of ventilators can be possible or not possible, depending on country regulations. The user may manually switch the fan to different speeds. This category may also include systems with mechanical supply in combination with natural exhaust chimneys, but this is less common.
5. Central unidirectional systems – DCV: Identical to system 4, but with demand control for supply and/or exhaust, based on the information of sensors positioned in ducts or in rooms.
6. Central unidirectional systems – DCV – smart: Identical to system 5, but moreover, there are smart features, e.g. self-calibrating of the system, fault detection, information on maintenance needs, feedback to the user, etc… The cases 'DCV' and 'Smart' are separately considered as they may have a substantial impact on the potential impact of policy options.
7. Central bidirectional system – manual: ventilation system with a central mechanical supply fan and a central mechanical exhaust fan. Usually the ventilation unit is equipped with a heat recovery system. The user may manually switch the fans to different speeds.
8. Central bidirectional system – DCV: Identical to system 7, but with demand control for supply and exhaust, based on the positions of sensors positioned in ducts or rooms
9. Central bidirectional system – smart: Identical to system 7, but moreover, there are smart features, e.g. self-calibrating of the system, fault detection, information on maintenance needs, feedback to the user, etc…
10. Local bidirectional system: systems consisting of decentralised bidirectional ventilation units, often with heat recovery system, located in dedicated rooms. Local systems may be easier applicable in renovation.

REFERENCES

Carrié, F.R., S. Charrier, A. Bailly. 2015. *Regulatory compliance checks of residential ventilation systems in France –* QUALICHeCK Factsheet #06, https://www.inive.org/projects/qualicheck

EC (European Commission). n.d. EU Buildings database. https://ec.europa.eu/energy/en/eu-buildings-database

EC (European Commission). 2014. Commission Regulation (EU) No 1253/2014 of 7 July 2014 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for ventilation units. *Official Journal of the European Union* L 337 25.11.2014, 8-26.

EC (European Commission). 2018. Directive (EU) 2018/844 of the European Parliament and of the council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. *Official Journal of the European Union L156 19.6.2018, 75-91.*

Durier, F. and V. Leprince. 2019. *Stock of ventilation systems in EU buildings and foreseen evolution for 2030, 2040 and 2050*, Technical study of the possible introduction of inspection of stand-alone ventilation systems in buildings, Final report,part-2.-https://op.europa.eu/en/publication-detail/-/publication/0bdd8b5e-b042-11ea-bb7a-01aa75ed71a1/language-en/format-PDF/source-search

Durier, F., P. Wouters, A. Janssens and Y. Decorte. 2019. *Selection of policy options for inspections of stand-alone ventilation systems and analysis of related potential impacts*, Technical study of the possible introduction of inspection of stand-alone ventilation systems in buildings, Final report, part 4. https://op.europa.eu/en/publication-detail/-/publication/0bdd8b5e-b042-11ea-bb7a-01aa75ed71a1/language-en/format-PDF/source-search

Durier, F., P. Wouters, M. De Strycker, G. Guyot, M. Sherman, V. Leprince, M. Urbani. 2019. *Existing regulations, standards and guidelines on the inspection of ventilation systems, and other relevant initiatives and projects*, Technical study of the possible introduction of inspection of stand-alone ventilation systems in buildings, Final report, part 1. https://op.europa.eu/en/publication-detail/-/publication/0bdd8b5e-b042-11ea-bb7a-01aa75ed71a1/language-en/format-PDF/source-search

Händel, C. 2010. Supplements to *Preparatory Study on Residential Ventilation* Lot 10. Fachinstitut Gebäude-Klima. https://www.eup-network.de/product-groups/preparatory-studies/completed/

Janssens, A., F. Durier and R. Carrié. 2014. *Securing the quality of ventilation systems in residential buildings: existing approaches in various countries.* Edited proceedings of the AIVC -TightVent International Workshop, 18-19 March, 2013. www.aivc.org

Maivel M., K. Kuusk, R. Simson, J. Kurnitski, T. Kalamees. 2015. *Overview of existing surveys on energy performance related quality and compliance* – Report from the IEE European project QUALICHeCK. https://www.inive.org/projects/qualicheck

Sustainable Energy Authority of Ireland (SEAI). 2019. *Quality ventilation is the key to achieving low energy healthy buildings* – Presentations at SEAI-AIVC Symposium, 27-28 March 2019, Dublin (Ireland). www.aivc.org

Verbeke, S., D. Aerts, G. Reynders, Y. Ma, P. Waide. 2020. Final report on the technical support to the development of a smart readiness indicator for buildings. https://smartreadinessindicator.eu/