Monitoring the energy- & IAQ performance of residential ventilation systems

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Long-term monitoring studies show that there are large differences in the IAQ- and energy performance of code compliant residential ventilation systems. Existing legal framework and assessment tools do not suffice to ensure the IAQ and properly asses the energy performance of ventilation systems.

Keywords: Monitoring, Residential Ventilation Systems, IAQ-performance, Energy performance.

MONICAIR

MONICAIR --MONItoring & Control of Air quality in Individual Rooms-- is a precompetitive field research project of a broad consortium of Dutch ventilation unit manufacturers and research institutes, supported by the Dutch government. The aim is to investigate the indoor air quality (IAQ) performance and energy characteristics of ten different mechanical ventilation solutions in dwellings that meet strict air-tightness standards and comply with current building regulations. Over a full year 62 residential dwellings were monitored, with in each habitable room sensors for occupancy, CO_2, relative humidity and air temperature. The power consumption of the mechanical ventilation units were also continuously monitored.

Key question the MONICAIR-consortium wanted to answer is "How well do code compliant ventilation systems perform in terms of IAQ and energy consumption in well insulated and air tight dwellings *in real life*, and how can their performance be further improved?" Past research has focussed on compliance with standards at nominal conditions -- and improvements are certainly necessary there [1] – but research on IAQ and energy performance of code compliant systems in real life conditions is scarce [2,3]. While housing stock is being improved in terms of insulation and air tightness as we speak, we do not know if ventilations systems perform sufficiently.

Selection of ventilation systems and dwellings

The manufacturing partners in the MONICAIR consortium produce both type C (MEV) and type D (MVHR) ventilation systems. Most commonly used in the Netherlands is ventilation system type C (mechanical extraction in wet rooms combined with natural air supply vents in habitable rooms). Ventilation systems type D (mechanical air extraction and mechanical supply) are applied in the new built sector when the budget allows for more expensive ventilation systems. Both types of ventilation systems are selected for the monitoring study, both with their specific variants and combinations as described in **Table 1**. The table describes per type of ventilation system 1) the air exchange provisions in both the wet rooms (bathroom, kitchen, toilets) as well as the habitable rooms (living room, bedrooms), 2) whether heat recovery is applicable and 3) what type of controls are used for the exhaust and supply provisions. The system type numbers refer to classification used in the Netherlands Standard NEN 8088-1, 2011 [4].

Selecting and finding suitable and comparable dwellings that also comply with the air tightness requirements (qv;10 ≤ 1.0 $dm^3/s.m^2$) proved to be challenging and could not have been done without the aid of the housing corporations. Not only the air tightness requirement, but also finding inhabitants that were prepared to allow sensors being installed in all rooms that monitor the IAQ and their behaviour for more than a year was very difficult. Eventually 62 families were prepared to make their dwelling available for the MONICAIR project. Before the start of the actual monitoring, all ventilation systems were checked and adjusted to the latest building code requirements, thus securing correct system specifications and ensuring that possible design- or installation errors do not influence the performance.

Data monitoring system

In every dwelling of the MONICAIR project the following sensors were installed:

- CO_2, RH (Relative Humidity) and air temperature sensors in all habitable rooms (living room, kitchen, bedrooms, study and utility room (if applicable). The sensors were mounted in the middle of the room approximately 1.5 m above the floor, away from doors and windows; the sampling frequency was set at five minutes.
- Occupancy sensors (PIR-type) in all habitable rooms

Table 1. Type of ventilation systems selected for MONICAIR.

System type		Section of house that is served	Air exchange provisions			Controls	
			Exhaust	Supply	Heat Rec.	Exhaust	Supply
	A.	Whole house	Nat. extraction in wet-rooms	Stnrd nat.supply vents in hab.rooms	No	No Control	Manual
Type C Systems	C.1	Whole house	Mech. extraction in wet-rooms	Stnrd nat.supply vents in hab.rooms	No	Manual 3-pos. switch	Manual
	C.2c	Whole house	Mech. extraction in wet-rooms	Wind contrl. nat. supply in hab.rooms	No	Manual 3-pos. switch	Manual
	C.4a	Whole house	Mech. extraction in wet-rooms	Wind contrl. nat. supply in hab.rooms	No	CO_2-sensor in living room	Manual
	C.4c	Whole house	Mech. extraction in all rooms	Wind contrl. nat. supply in hab.rooms	No	CO_2/ RH cntrl in all hab.rooms	Manual
Type D Systems	D.2	Whole house	Mech. extraction in wet-rooms	Mech. supply in hab.rooms	Yes	Manual 3-pos. switch	
	D.5a	Whole house	Mech. extraction in wet-rooms	Mech. supply in hab.rooms	Yes	Manual 3-pos. switch with CO_2-contrl in 2 zones	
	D.5b	Whole house	Mech. extraction in all rooms	Mech. supply in hab.rooms	Yes	CO_2 and RH -controlled ventilation in all rooms	
	D.x	Whole house	Mech. extraction in all rooms	Mech. supply in con.spaces	Yes	CO_2- & RH control in all hab. rooms	
Comb. of systems	X1/C	Living section: D	Mech. extraction in hab.rooms	Mech. supply in hab.rooms	Yes	CO_2 and RH -controlled ventilation in living room	
		Sleeping section:C.2c	Mech. extraction in wet-rooms	Wind contrl. nat. supply in bedrooms	No	Manual 2-pos. switch	Manual
	X1/A	Living section: D	Mech. extraction in hab.rooms	Mech. supply in hab.rooms	Yes	CO_2 and RH -controlled ventilation in living room	
		Sleeping section: A	Nat. extraction in wet-rooms	Wind contrl. nat. supply in bedrooms	No	No control	Manual

- RH-sensor in the bathroom with a sampling frequency of five minutes
- Sensors monitoring the power consumption of the mechanical ventilations units and kitchen hoods.
- Meteorological data on outdoor temperature, relative humidity, wind speed, wind direction and air pressure of the most nearby weather stations was gathered.

Per cluster of dwellings all data of each house is gathered through rf-communication and stored on a local PC. Through an FTP connection the data stored on local PCs is regularly copied onto the centralized MONICAIR SQL database.

Data analyses

For a period of more than a year large amounts of data were gathered about the ventilation systems and their real life performance on indoor air quality and energy consumption, as well as data on consumer behaviour regarding the preferred temperature per habitable room, operation of ventilation units, use of kitchen hoods, and hot water consumption pattern. With these data various angles of data analysis are possible. Given the focus and resources related to the first part (WP1a) of the MONICAIR project, the analysis here is restricted to the IAQ- performance and the energy performance during heating season.

Indicator for the IAQ performance

To assess the IAQ performance of ventilation systems the measured CO_2-concentration in the individual habitable rooms is used as leading parameter. The CO_2-concentration is generally accepted as the key indicator for the existing ventilation rate per person during presence [5] and consequently for the occurring IAQ levels. The following procedure is used to assess the IAQ in the various habitable rooms:

a) Determine for each habitable room in each dwelling the number of hours per day that the CO_2-concentration is above 1200 ppm in unit [hours/day]. The limit value of 1200 ppm corresponds to the IAQ category IV (= the lowest IAQ level) as described in prEN 16798-1:2015 [6].
b) Determine for each habitable room in each dwelling the average concentration with which the CO_2-limit of 1200 ppm is exceeded in unit [ppm/h].
c) Calculate the CO_2-excess dose per heating season in kppmh by multiplying the outcome of a) with the outcome of b) and then multiplying the result with the number of days in a heating season (212) and dividing it by 1000 to convert the ppm-figure to kppm.
d) Sum up all the CO_2-excess doses per habitable room per dwelling and divide it with the number of inhabitants of that specific dwelling to determine the average achieved IAQ level per person.

Indicator for the Energy performance

The indicator for the Energy performance of ventilation systems is obtained using the following procedure:

I) Determine the *hourly* thermal energy losses for mechanical ventilation on the basis of the hourly average ventilation rate and the hourly average differences between indoor and outdoor temperature and humidity. For systems with heat recovery this figure is corrected with an average real-life efficiency of 80%.
II) Calculate the *daily* thermal energy losses by adding up the hourly averages and relate it to the daily av. temperature difference between in- and outdoors ($\Delta T_{in\text{-}out}$) of that specific day.
III) From II) the daily average energy loss is derived for the heating season average temperature difference $\Delta T_{in\text{-}out}$ of 13°C (being the average indoor temperature of 19°C minus average outdoor heating season temperature in the Netherlands of 6°C).
IV) The yearly primary energy consumption is determined by multiplying the outcome of III) with the number of days in an heating season (212), dividing it by the average heating system efficiency of 85% and adding up to this figure the total power consumption of all ventilation units during heating season, after converting it to primary energy.
V) Divide the outcome of IV) with the total heated surface area of the dwelling to obtain the average primary energy consumption of the mechanical ventilation system per m² during heating season.

Note 1: The calculations for a) and b) are made with a resolution of five minutes and then summarised to obtain either the number of hours per day or the excess value per hour.
Note 2: The calculation procedure for the IAQ-performance is comparable to the methodology used in the declaration of equivalence of the VLA [7] for determining the Air Quality Index.
Note 3: Energy consumption related to cross ventilation (air that enters the dwelling through infiltration or airing on one façade and leaves through another façade) is not included; also internal and solar gains are not included in this assessment of the energy performance.

Results

The results on CO_2-concentrations and energy consumption are summarized in **Figure 1**. In the graph the diamond markers represent system averages on CO_2-excess dose per person (product of duration and amount of excess above 1200 ppm during heating season). The vertical lines represent the standard deviation of a group of ventilation systems (both refer to the vertical axis of the graph). On the horizontal axis the system averages for energy consumption of ventilation systems in total primary energy per m² heated surface during heating season is indicated. The standard deviation on energy consumption is limited and therefore not displayed in the graph (see lit.1 for further explanation of ventilation system types).

For further details on the results of the monitoring study see lit. [8] and [9].

Apart from ventilation system A (which was added at the request of housing associations because they represent a significant share of the housing stock) all other ventilation systems are code compliant. The large variations both in CO_2-excess dose per person and in the standard deviation illustrate that there are considerable differences in the IAQ-performance of code compliant ventilation systems. The large extent of these differences in achieved air exchange rates was not fully anticipated, especially given the fact that all ventilation systems achieved overall air exchange rates well above 10 l/s per person, which complies with the highest IAQ category (prEN 16798-1:2015) . The data in fact illustrates to what extent the ventilation systems are capable of achieving the requested air exchange rates per person in the various habitable rooms. Ventilation systems that apply a mechanical component in the air exchange provisions in habitable rooms (either supply, exhaust or both) perform significantly better in that respect than systems with only natural air exchange provision in habitable rooms. Both on CO_2-excess dose per person and on its standard deviation the systems with a mechanical component in the habitable rooms outperform the systems with only natural provisions. The latter systems show large variations in their IAQ-performance due to the fact that they have insufficient control over the air exchange in the habitable rooms. These systems would require frequent and targeted interventions from active occupants, but the monitoring results show that this type of behaviour was not exhibited.

Systems with a mechanical air exchange component in the habitable rooms, to a lesser extent, also vary in their IAQ-performance due to the fact that some units or individual fans are temporary switched off because of noise or draught.

In respect to the energy performance of the investigated ventilation systems, it may be concluded that the real life energy consumption is not in line with the results of the EPBD calculation methods. The real life measurements result in a different relative ranking than according to EPBD assessment methods. This is mainly caused by differences in the assumed and real life system operation. Apart from that, there are ventilation systems with a certain type of automated CO_2-control, that actually perform considerably worse in real life than according the assessment methods. Again, the assumptions on the effect of the concerning CO_2-control on which the EPBD assessment is based, differs from real life operation.

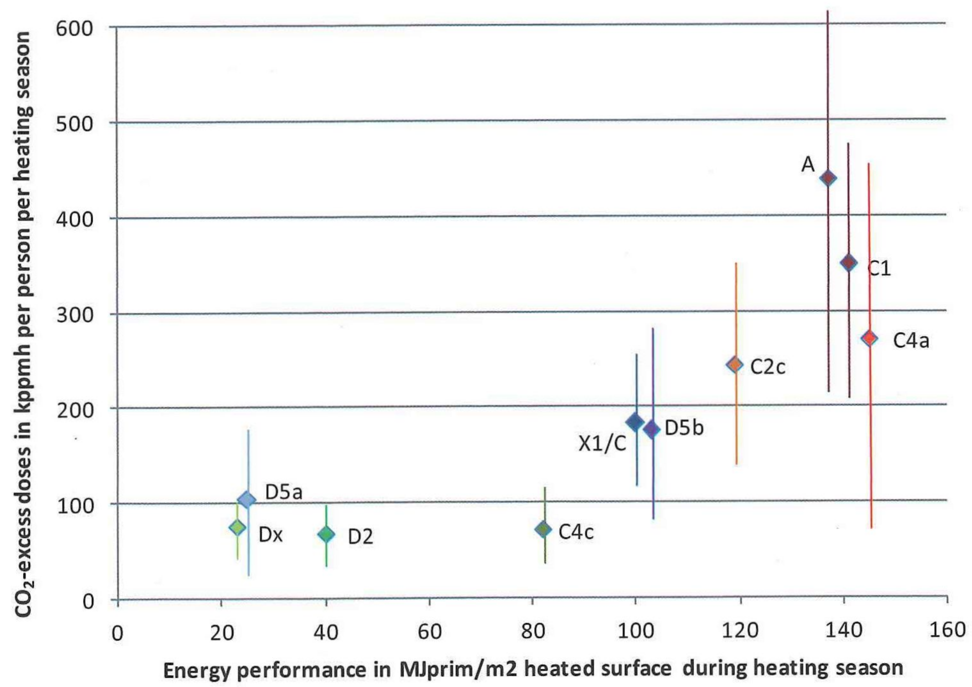
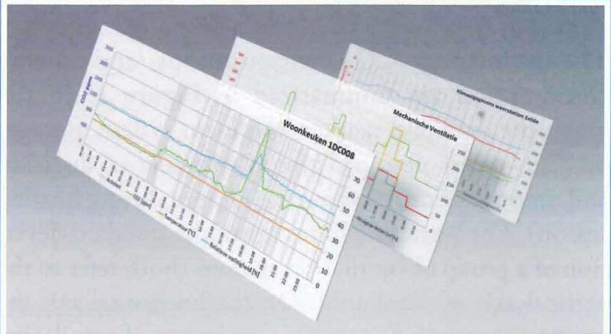


Figure 1. Ventilation system averages and standard deviation on CO_2-excess dose and energy performance.

Conclusions

Clearly the (implicit) assumption that all code compliant ventilation systems perform comparably on IAQ cannot be substantiated by these findings. There are significant differences related to the IAQ-performance that are currently not recognized. The existing legal framework does not require any assessment of the IAQ-performance. Only the energy performance of the ventilation system is assessed. But what is the meaning is of an assessment of the energy performance when the performance on its primary function is not known? On top of that this long-term monitoring study shows that the real life energy-performance of ventilation systems is not in line with the results of the EPBD assessment methods.

Current legal framework and assessment tools therefore give an incorrect representation and ranking of code compliant ventilation systems and unjustly favour certain systems. Further refinement of the legal framework and performance assessment tools will be necessary to correct this. Only with a proper assessment of the IAQ- and energy performance a true representation of the systems can be given. ■



MONICAIR

The following parties participate in the MONICAIR consortium:

Manufacturers:
- Brink Climate Systems BV
- ClimaRad BV
- Honeywell, HCCP
- Itho Daalderop Nederland BV
- Zehnder Group Nederland BV

Research and consultancy agencies:
- Nieman Raadgevende Ingenieurs BV
- VHK (Van Holsteijn en Kemna) BV

Knowledge and research institutes:
- TNO
- TUDelft –OTB

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