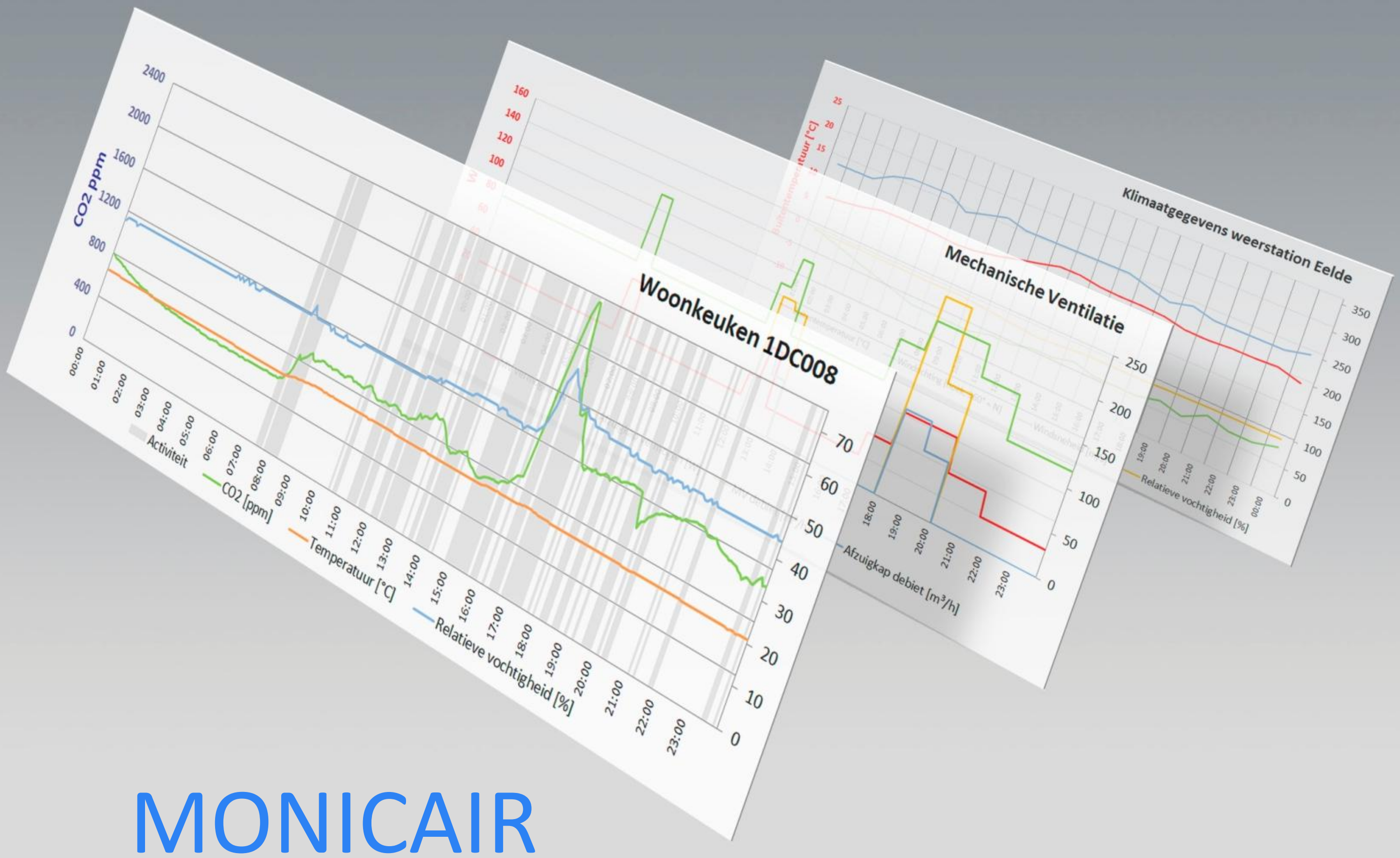

MONICAIR

MONItoring & Control of Air quality in Individual Rooms

Final Report WP1a

Results of a monitoring study into the indoor air quality and energy efficiency of residential ventilation systems.

Consortium MONICAIR part A
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Ir. W.L. Li

Delft, December 2014

MONICAIR is a research project initiated by the Dutch Ventilation Industry and co-financed by the Dutch Ministry of Economic Affairs within the framework of TKI (Top consortia for Knowledge & Innovation).

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MONICAIR Consortium

The Monicair field study was carried out by leading manufacturers, consultancies and research centres that are all active in the ventilation sector.

The Monicair consortium comprises the following partners:

Brink Climate Systems BV

ClimaRad BV

Honeywell Customized Comfort Products

Itho Daalderop Nederland BV

Nieman Raadgevende Ingenieurs BV

Technische Universiteit Delft, OTB

TNO

Van Holsteijn en Kemna BV

Zehnder Group Nederland BV

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Management Summary

Monicair is one of the first detailed and prolonged monitoring studies into the performance of correctly fitted ventilation systems in terms of indoor air quality and related energy efficiency in the field. For a whole year, the indoor air quality of all individual rooms in 62 dwellings was monitored every five minutes. The study also continually measured mechanical air flow rates and the real-life energy consumption of the ventilation units. The aim of this study is to gain greater insight into actual performance so ventilation systems can be optimised further. Although the study cannot be considered representative for all aspects (the random sample of 62 dwellings is too small for this), the results are extremely valuable and instructive and provide a clear picture of how well ventilation systems work and perform in practice. Based on an extensive analysis of the sizeable Monicair database, the following insights may obtained about how well ventilation systems function in practice during the heating season.

Major differences in indoor air quality

CO_2 concentrations are an excellent indicator for occurring ventilation rates during presence and consequently for IAQ levels in habitable rooms. The CO_2 - excess doses (= product of the duration and amount of CO2-concentrations above 1200 ppm) of ventilation systems that fully comply with Dutch building regulations show major differences in practice, both between the systems themselves and between individual dwellings fitted with the same ventilation system. The CO_2 - excess doses measured for dwellings with mechanic ventilation systems vary from 0 to 852 kppmh per person per heating season. The highest value was measured in a dwelling with system A and was 997 kppmh. The period of time over which CO_2 concentrations were measured to be too high varied from 0 to over 8 hours per person per day. The table below shows the average values per group of ventilation systems, with the standard deviation also stated in addition to the CO_2-excess dose per heating season.

Ventilation systems	Number of hours a day with CO_2>1200 ppm	Average excess value >1200 ppm CO_2	Average CO_2-excess doses per dwelling per day	Average CO_2-excess doses per dwelling per heating season	Average CO_2-excess dose per person per dwelling per heating season with standard deviation	
	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]	[kppmh/pp/ht.ssn]	stndrd dev.
A	9.76	689	6723	1425	442	*438*
C1	10.95	512	5600	1187	349	*276*
C.2c	12.42	344	4267	905	244	*216*
C.4a	7.62	731	5570	1181	271	*389*
C.4c	3.13	247	773	164	72	*78*
D.2	3.52	291	1024	217	68	*32*
D.5a	2.65	494	1308	277	105	*156*
D.x	3.63	199	718	152	76	*32*
D.5b	4.40	509	2239	475	183	*199*
X1/C	6.84 *(1.45)*	320 *(217)*	2186 *(315)*	463 *(67)*	175 *(30)*	*139 (33)*
X1/A	2.82 *(1.27)*	346 *(302)*	976 *(384)*	207 *(81)*	167 *(61)*	*124 (47)*
Figures between brackets relate to the performance of decentralised heat-recovery units in living rooms and connected areas						

Table 1. Results for CO2- excess doses in habitable rooms >1200 ppm, average per group of ventilation systems

Note 1: System C4c relates to the variant with mechanical extraction in all wet rooms and all habitable rooms.
Note 2: The CO2- excess doses calculated here and the excess dose per person are lower than the excess that actually occurred, as the calculation method used does not take account of the fact that multiple individuals may be exposed to the same CO2- excess doses in a room (main bedroom, living room). As a rule, if the total dose of exposure time to excess levels is divided by the number of occupants, this results in an excessively low value. Please take account of this when interpreting the results.

Both average CO2- excess doses s and the related standard deviation increase as the ventilation system has less control over ventilation volumes in habitable rooms. This is the case with systems A, C1, C2c, and C4a, with habitable rooms fitted with natural air supply and extraction facilities (ventilation grilles and overflow components).

Ventilation systems with a mechanical component in the habitable rooms have lower CO2- excess doses with a lower standard deviation.

In terms of excess and/or insufficiency in relative humidity during the heating season, the differences between the ventilation systems are limited. Periods with an excessively high RH (>70%) appear almost exclusively in the bathroom and are as a rule shorter than an average of 2 hours a day (the exception to this being a few dwellings with natural extraction from the wet rooms (system A).

Periods with low humidity (RH <30%) occur in all rooms and are as a rule slightly longer than 5 hours a day per room on average.

The performance of ventilation system has improved over the course of time (A, C, C4c, D, X1)

The study results show a picture of improving indoor air quality as the latest ventilation systems are used. The underlying reason for this is that newer ventilation systems give a more prominent position to *mechanical* supply and extraction facilities. The oldest system (system A) only uses natural supply and extraction facilities, both in wet rooms and habitable rooms. Dwellings with system C use a mechanical extraction component in the wet rooms, giving them better scores than dwellings with system A.

These traditional systems (system C) are perfectly capable of refreshing the required volumes of air throughout the dwelling and to keep air quality in the wet rooms (RH value) within the specified limits. However, because habitable rooms are only fitted with natural supply and extraction components (ventilation grilles and overflow components), these systems have proven less capable of translating ventilation volumes – that in principle should be sufficient for healthy air-quality levels – into correct ventilation volumes in the habitable rooms. The result of this is that, for a significant amount of time spent in the habitable rooms, ventilation volumes are too low. The newer variants of this (system C4c), but also systems D and X1, also use mechanical components in habitable rooms, ensuring ventilation volumes at the level of habitable rooms. These more up-to-date systems therefore provide better indoor air quality in habitable rooms than systems with only natural supply and extraction facilities in the habitable rooms.

Airtightness of dwellings has little influence on air quality

The assumption that leaky dwellings (dwellings with a high qv10 value) show a better air quality on average is not confirmed by the Monicair study results. On the contrary, the actual results show the opposite. However, this has nothing to do with the dwelling's airtightness, but with the fact that better ventilation systems (ventilation systems with mechanical components in the habitable rooms) are used in airtight dwellings.

And the results of the airtightness tests also indicate that the “leaks” as a rule are not found in the habitable rooms, so have little or no influence on air quality there.

Occupants show no reactive ventilation behaviour

Although occupants show certain habits or fixed patterns of controlling ventilation components (use of ventilation grilles, extractor hoods and position switches), they do not show any reactive ventilation behaviour. In habitable rooms, CO_2 concentrations can rise to over 3500 ppm without occupants reacting to this and taking action by turning the mechanical ventilation unit to a higher setting, for instance. It is even true that, for manually controlled systems, the ventilation rates in setting 1 of the mechanical ventilation unit are more or less typical of the average ventilation rates realised. The temporary higher flow rates that some occupants switch on when showering only have a limited effect on total average ventilation rates.

Most families show a ventilation behaviour that runs according to a more or less fixed pattern of using ventilation grilles and/or vent windows in the bedrooms and operating the extractor hood and position switch when cooking and showering. This behaviour can vary per dwelling.

Unintended reactive behaviour is observed in a few systems with a mechanical air supply and/or extraction component in the habitable rooms. Due to problems with noises and/or draughts the ventilation system is used to compensate, for instance by closing the supply valve, switching off the central supply fan or temporarily turning off the (decentralised) heat-recovery unit.

Correlation ventilation rates and air quality larger for systems with mechanical component in habitable rooms

Ventilation systems with a mechanical component in the habitable rooms show a lager correlation between realised ventilation rates per person and the measured CO2- excess doses that systems with only natural supply and extraction facilities in the habitable rooms.

The latter of these systems shows a strong correlation between the number of occupants and CO2- excess doses . In other words, for systems A, C1, C2c and C4a, the more occupants, the higher the CO2- excess doses .

Ventilation effectiveness can be increased further by using CO_2 sensors, on the condition that these sensors regulate a mechanical component in the same habitable room in which their measurements are taken. CO_2 sensors not linked to a mechanical supply and/or extraction component in the habitable room in which the sensor takes its measurements, do not always show better air quality than the same systems without a CO_2 sensor (compare system C4a versus C2c). The same goes for systems with a CO_2 sensor not located in a habitable room but in a connecting space and that uses air transport via overflow components to regulate ventilation in the adjacent habitable rooms (compare bedrooms of D5a with those of D2).

Major differences in energy efficiency

Assuming a realistic efficiency of about 80% for the heat-recovery system as a whole, the mechanical ventilation systems D2, D5a and Dx use an average of 29 MJ per m^2 of surface area in primary energy (fan power and thermal energy content of exchanged air). This excludes energy loss due to infiltration, drainage and cross-ventilation. If EN13141-7/8 efficiencies are used for the heat-recovery units, the average primary energy consumption is about 20 MJ per m^2. The mechanical systems C1, C2c and C4a on the other hand use an average of 122 MJ per m2.

System D thus uses an average of 75% less primary energy than system C. Moreover, the measured air-quality performance of system D is better than that of a traditional system C by a factor of 3 (89 versus 290 kppmh per person per heating season).

Ventilation-system performances can and must improve

With this study, Monicair provides first insights into the real life performance of ventilation systems in terms of indoor air quality. Although the systems gradually improve over time, there are several system features that can be improved. In practice, systems with only natural air supply and extraction facilities in habitable rooms are not very good at regulating ventilation volumes in these rooms, resulting in higher CO_2- excess doses . Systems with a mechanical component in the habitable rooms perform better on that point but induce occupants to take undesirable measures due to irritating noise or draughts. Furthermore, the study confirms that occupants are not able to react adequately to higher CO_2 concentrations, simply because this is not observed due to adaptation. Ventilation systems therefore must do this job as effectively as possible, without the need of human intervention.

In terms of energy efficiency, the systems with heat recovery clearly perform better than the systems without heat recovery. If we also include the better performance in terms of indoor climate and use this as reference, the differences in performance between systems are even bigger.

Recommendations

The study that was carried out within this work package of the Monicair project, is limited to systems that are fitted and set up correctly and that comply with buildings regulations. In that sense, the results are illustrative for just a limited segment of the high-end market. Many more field studies like Monicair are required to gain a representative idea of the full housing stock, including the larger share of the dwellings in which the ventilation system is not correctly set up.

The ventilation systems currently selected and fitted to new buildings and large-scale renovations all comply with Dutch building regulations, but in practice show significant differences in their performance in terms of indoor air quality. These differences remain undefined for now, and the energy assessment in line with NEN7120/NEN8088 implicitly assumes that the systems all realise the same indoor air quality. It is recommended to identify these differences and to stop comparing apples and pears.

One idea might be to introduce IAQ classes that clearly indicate which CO_2 bandwidths apply and what the maximum permitted limit is. Field studies combined with modelling could form the basis for the assessment of ventilation systems at this point.

Another option that also uses the combination of field studies and modelling is to establish which air flows a given ventilation system needs to realise a predefined air quality. Based on the already calculated ventilation volumes, the energy requirements of the system can then be specified. This allows the energy consumption to be determined based on the same air-quality performance.

It is also recommended to compare the current methodology for the energy assessment of ventilation systems (NEN7120/NEN8088) with the outcome of the Monicair study and, where necessary and useful, to *tune* these calculation models to the values as measured in practice.

The Dutch building regulations designate NEN1087 as the formal method for specifying the layout of air supply and exhaust facilities. It is recommended to re-examine this method of specification carefully, as it stems from 2001, and to assess whether it requires modification.

Finally, it is recommended to use the results from this Monicair study when developing future ventilation systems. In work package 3a of this TKI-EnerGo project, guidelines will be drawn up based on the study results that can be used by ventilation manufacturers to plan their new development activities.

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1. Introduction

The urban environment is responsible for around 40% of the total European energy consumption, with spatial heating being the main item (>50%). So it is not surprising that European legislation (EPBD and EcoDesign) are partly geared towards raising the insulation levels and air-tightness of homes and other buildings. As a result of this, natural infiltration is decreasing further and indoor air quality is becoming more dependent on the quality of the ventilation system. One key question in this regard is: “How well do ventilation systems perform in practice in terms of indoor air quality and energy efficiency in modern well-insulated and draught-free homes, and how can this performance be improved further?”
Studies carried out so far mainly focus on investigating whether ventilation systems are fitted in compliance with Dutch building regulations. Their key conclusions are that there is a great deal of room for improvement on many points, especially in terms of fitting, programming and commissioning [1].
However, studies focusing more on indoor air quality actually realised per room, and on the related energy efficiency of ventilation systems that comply fully with building regulations, are very few and far between [2,3]. With a housing stock that is gradually improving in terms of insulation and air tightness, it is time to bridge this gap in our knowledge. Clarity needs to be obtained on the question of whether ventilation systems that comply fully with building regulations are capable of realising an acceptable indoor air quality at all times in the rooms in which occupants spend most of their time.

To answer this crucial question, a consortium was set up (comprising manufacturers, specialised engineering consultancies and research centres) that has initiated the MONICAIR project (MONItoring & Control of Air quality in Individual Rooms) to provide answers. MONICAIR is a 1.6 million euro precompetitive field study project partly funded by the consortium partners and partly by the Ministry of Economic Affairs within the TKI-EnerGo framework (Top consortia Knowledge and Innovation).
One aim of the MONICAIR project is to monitor actual indoor air quality for a whole year in *all individual habitable rooms*, while occupants are both present and absent, in more than sixty dwellings that are all fitted with properly-programmed and building code compliant ventilation systems. The second aim is monitor the energy consumption of these ventilation systems. This information makes is possible to link each ventilation system's IAQ performance to its related energy consumption.

The assumption is that a comprehensive analysis of the log data thus obtained will assist in the identification of system parameters that consortium partners can use to improve the IAQ- and energy-efficiency of their ventilation systems. Further the knowledge gained through this study will be used to further tighten the current calculation and specification methods for estimating the IAQ and energy performance of ventilation systems (EPA and EPC calculations).

This report contains the final results of work package WP1a, and covers the analyses of a full year of monitoring data of 62 dwellings with ten different and these days commonly used ventilation systems. All systems were programmed and checked for building code compliance prior to commencement of the study to prevent design, fitting or programming errors affecting the measurement data.

2. Study methodology and procedure

This chapter describes the choices made in the field study. It explains the selection of the ventilation systems and the related dwellings, and gives further details of the data monitoring system used by the study. Finally, it elucidates the procedures used for converting log data (100 million data points) into usable information.

2.1
Selection of ventilation systems

The manufacturers taking part in the consortium produce ventilation systems of type C, type D and type X. Traditional ventilation systems of type C are systems with natural supply (ventilation grilles) in the habitable rooms (living rooms and bedrooms) and mechanical extraction in the wet rooms (bathroom, kitchen and toilet). The idea is that the outdoor enters the dwelling in the habitable rooms and is then transported to the wet rooms via overflow components (gap under closed dividing doors) or via open dividing doors and then mechanically extracted and exhausted outside the dwelling.
Ventilation systems of type D are systems that supply outdoor air to the habitable rooms mechanically (via supply valves), and then also extract air from the wet rooms mechanically. Here too the air supplied to habitable rooms must be transported via overflow components or open dividing doors from the habitable rooms to the wet rooms, from where it is then extracted. These systems use heat recovery so the extracted air transfers its heat to the outdoor supply air, as this significantly reduces energy consumption for indoor heating.
Ventilation systems of type X are basically a mix of both systems. A local ventilation unit with heat recovery is fitted in the living room. This unit ensures both the supply of fresh outdoor air and the extraction of stale air using heat recovery. The sleeping area is ventilated using system C, with the air flows extracted from wet rooms modified to factor in the size of the bedrooms.

System C is the most commonly used system in the Netherlands, not only in existing housing stock, but also in new construction and renovation projects. This is simply down to the fact that it is a relatively cheap system that complies with Dutch building regulations and – with a little creativity – can also be made to meet the EPC (energy) requirements. Despite the high capital outlay, system D is being increasingly used in new construction due to its energy efficiency. System X is used in both new construction and renovation projects and tries to combine both benefits (energy efficiency and affordability / simplicity).

All these types of ventilation systems and their specific variants were selected for the monitoring study. Table 2.1.1 provides a further specification of the selected systems. This indicates, system for system, the ventilation facilities in each room, which type of control is used and whether or not heat recovery is used. The type numbers refer to the classification used in NEN8088-1, 2011.

At the request of the housing associations involved, dwellings were also included that use system A (homes with natural supply facilities in habitable rooms and natural facilities from wet rooms). A group of homes was therefore selected with fully natural facilities (System A), as well as a group of dwellings with only fully natural ventilation in the sleeping area and in the living room with a decentralised heat-recovery unit (System X1/A).

Table 2.1.1:
Type ventilation systems that are selected for the monitoring study MONICAIR part A.

System type		Part of dwelling served	Ventilation provisions			Controls	
			Extraction	Supply	Heat recovery	Extraction	Supply
Type A	**A**	Whole dwelling	Natural extraction from wet rooms	Natural supply grilles in habitable rooms	No	None	Manually controlled
Type C	**C.1**	Whole dwelling	Mechanical extraction from wet rooms	Natural supply grilles in habitable rooms	No	3-position switch	Manually controlled
	C.2c	Whole dwelling	Mechanical extraction from wet rooms	Pressure-regulated natural supply in habitable rooms	No	3-position switch	Manually controlled
	C.4a	Whole dwelling	Mechanical extraction from wet rooms	Pressure-regulated natural supply in habitable rooms	No	CO_2 sensor. living room	Manually controlled
	C.4c	Whole dwelling	Mechanical extraction from all rooms	Pressure-regulated natural supply in habitable rooms	No	CO_2 & RH control in all rooms	Manually controlled
Type D	**D.2**	Whole dwelling	Mechanical extraction from wet rooms	Mechanical supply to habitable rooms	Yes	3-position switch	
	D.5a	Whole dwelling	Mechanical extraction from wet rooms	Mechanical supply to habitable rooms	Yes	3-position switch combined with CO_2 control (2-zone sensing)	
	D.5b	Whole dwelling	Mechanical extraction from all rooms	Mechanical supply to habitable rooms	Yes	CO_2 and RH controlled regulation of ventilation flows	
	D.x	Whole dwelling	Mechanical extraction from all rooms	Mechanical supply to connecting spaces	Yes	CO_2 and RH controlled regulation of ventilation flows	
Hybrid	**X1/C**	Living area: D	Mechanical extraction from living rooms	Mechanical supply to habitable rooms	Yes	CO2 and RH controlled regulation of ventilation flows	
		Sleeping areas: C.2c	Mechanical extraction from wet rooms	Pressure-regulated natural supply in bedrooms	No	3-position switch	Manually controlled
	X1/A	Living area: D	Mech. extraction in habitable rooms	Mechanical supply to habitable rooms	Yes	CO_2 and RH controlled regulation of ventilation flows	
		Sleeping areas: A	Natural extraction from wet rooms	Pressure-regulated natural supply in bedrooms	No	None	Manually controlled

2.2.

Selection of dwellings

Selecting and realising suitable monitoring locations for this study turned out to be a serious challenge. And it probably would not have been possible within the given time scale without the help of the housing associations involved. The first requirement was to find clusters of similar dwellings that use one of the selected ventilation systems (they also had to be homes that were fairly close together owing to the range of the data-communication equipment used).

The second condition related to occupants themselves, who had of course to be willing to participate in the study by allowing sensors to be placed in every room that continually logged information about indoor air quality and energy consumption. Here too the backing and cooperation of the housing associations involved proved indispensable.

The third requirement related to the air tightness of the dwelling – the $q_{v;10}$ value – which preferably had to be equal to or less than 1.0 dm^3/s.m^2. Many initially selected clusters of homes that had a $q_{v;10}$ of ≤ 1.0 dm^3/s.m^2 on paper fell short of this during a *blower door* test. Eventually this strict requirement was eased slightly to dwellings with a $q_{v;10}$ value of around 1.0 dm^3/s.m^2. A *blower door* test was carried out in one dwelling for each cluster, with the result taken as representative for the other homes in that cluster.

Finally, there was an express requirement that a certain type of HE boiler was fitted in all participating dwellings that would allow all instantaneous gas consumption for heating and hot tap water to be logged. This requirement resulted in the combi boiler being replaced in a number of homes specially for this study.

In the end, 62 families from as many homes were found who were willing to participate in the MONICAIR project. Table 2.2.1. provides an anonymity overview of the dwellings and number of occupants per ventilation system.

Table 2.2.1: Typing of homes/families participating in the MONICAIR study, divided into type of ventilation system

Type Vent. Syst.	No.	Dwelling type	Ag [m2]	Number of occupants	$q_{v;10}$ [dm^3/s.m^2]	Number of monitored habitable rooms (incl. open kitchen)	Number of monitored wet rooms
Type A	A-1	block of flats	56.13	1	1.568	3	2
	A-2	terraced house	66.07	2	1.242	4	2
	A-3	end of terrace	85.30	4	3.082	4	2
	A-4	terraced house	85.30	3	3.713	4	2
	A-5	terraced house	85.30	2	3.713	4	2
Type C.1	C1-1	end of terrace	70.00	1	2.637	3	2
	C1-2	end of terrace	68.00	2	2.637	3	2
	C1-3	terraced house	70.00	3	2.637	3	2
	C1-4	terraced house	103.36	4	1,312	4	2
	C1-5	terraced house	103.36	3	1,312	4	2
	C1-6	end of terrace	125.62	4	1,312	5	2
Type C.2c	C2c-1	terraced house	96.12	1	1.003	4	1
	C2c-2	terraced house	96.12	3	1.003	4	1
	C2c-3	terraced house	96.12	4	1.003	4	1
	C2c-4	end of terrace	96.12	3	1.003	4	1
	C2c-5	end of terrace	96.12	5	1.003	5	1
	C2c-6	terraced house	96.12	4	1.003	5	1

Type Vent. Syst.	No.	Dwelling type	Ag [m2]	Number of occupants	$q_{v;10}$ [dm^3/s.m^2]	Number of monitored habitable rooms (incl. open kitchen)	Number of monitored wet rooms
Type C .4a	C4a-1	terraced house	66.07	2	1.242	4	2
	C4a-2	end of terrace	66.07	2	1.242	4	2
	C4a-3	terraced house	66.07	2	1.242	3	2
	C4a-4	terraced house	66.07	5	1.242	4	2
Type C.4c	C4c-1	end of terrace	108.33	1	1.440	4	1
	C4c-2	terraced house	108.33	1	1.440	3	1
	C4c-3	terraced house	108.33	2	1.440	4	1
	C4c-4	terraced house	108.33	2	1.440	3	1
	C4c-5	end of terrace	108.33	1	1.440	3	1
	C4c-6	end of terrace	108.33	3	1.440	4	1
Type D.2	D2-1	semi-detached	139.86	2	0.602	4	1
	D2-2	semi-detached	110.53	5	0.602	4	1
	D2-3	semi-detached	135.63	2	0.602	4	1
	D2-4	semi-detached	146.01	4	0.602	4	1
	D2-5	terraced house	91.90	4	0.602	4	1
	D2-6	terraced house	91.90	3	0.602	4	1
Type D.5a	D5a-1	terraced house	92.92	1	0.826	4	1
	D5a-2	semi-detached	119.85	2	0.854	4	1
	D5a-3	semi-detached	92.92	2	0.625	4	1
	D5a-4	terraced house	92.92	3	1.283	4	1
	D5a-5	semi-detached	92.92	2	0.826	4	1
	D5a-6	semi-detached	119.85	3	0.625	4	1
	D5a-7	end of terrace	122.26	2	0.150	5	1
	D5a-8	terraced house	122.26	3	0.150	5	1
	D5a-9	terraced house	122.26	3	0.150	5	1
	D5a-10	terraced house	122.26	1	0.150	5	1
Type D.5b	D5b-1	end of terrace	66.07	3	1.242	3	2
	D5b-2	terraced house	66.07	2	1.242	3	2
	D5b-3	end of terrace	66.07	1	1.242	3	2
	D5b-4	terraced house	66.07	2	1.242	3	2
Type Dx	Dx-1	terraced house	108.33	2	1.138	4	1
	Dx-2	end of terrace	108.33	2	1.138	4	1
	Dx-3	end of terrace	108.33	2	1.138	4	1
Type X1/C	X1C-1	terraced house	66.07	4	1.242	4	2
	X1C-2	terraced house	66.07	2	1.242	4	2
	X1C-3	end of terrace	66.07	2	1.242	4	2
	X1C-4	terraced house	66.07	1	1.242	4	2
	X1C-5	end of terrace	66.07	2	1.242	4	2
Type X1/A	X1A-1	block of flats	56.13	1	1.568	3	2
	X1A-2	block of flats	56.13	2	1.568	3	2
	X1A-3	block of flats	56.13	1	1.568	3	2

Before commencing actual monitoring, the ventilation rates of the ventilation systems were checked and tuned to applicable building regulations. Electricity consumption was also measured for correctly programmed ventilation rates.

2.3
Intake interviews with occupants

Before the data monitoring started, intake interviews were held with occupants. The aim of this was to get an impression of the perception people have of ventilation and their own behaviour in terms of activities that can affect indoor air quality. This section provides an impression of the results of these intake interviews. Note: during this study no qualitative information was gathered of homes with system Dx and system X1/A. So these systems are not included in the qualitative considerations below.

2.3.1
General picture of ventilation systems

Occupants associate ventilation systems with the following terms:

Figure 2.3.1.1 Word cloud of terms associated with ventilation systems

Occupants have the following value association with ventilation systems:

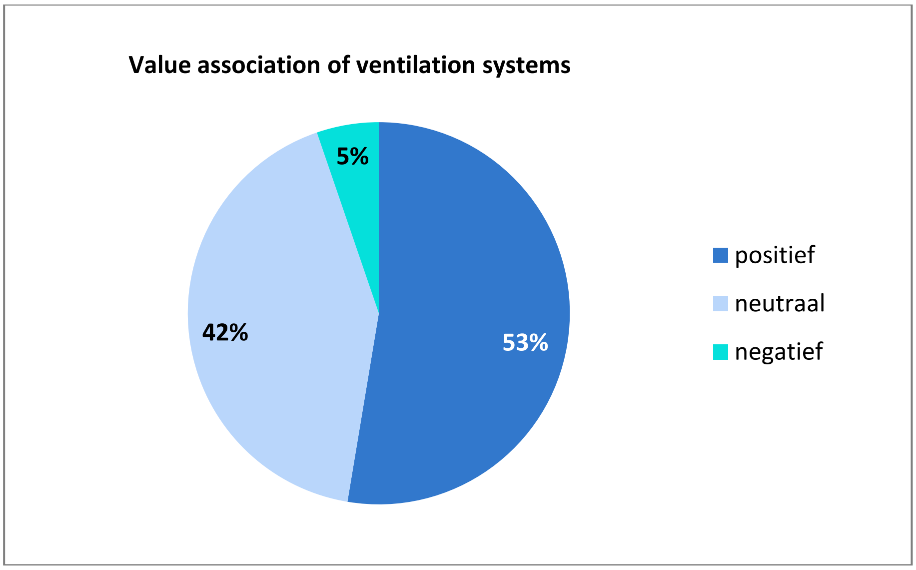


Figure 2.3.1.2 Value association of ventilation systems

The following valuation is given about the freshness of the air in the different rooms

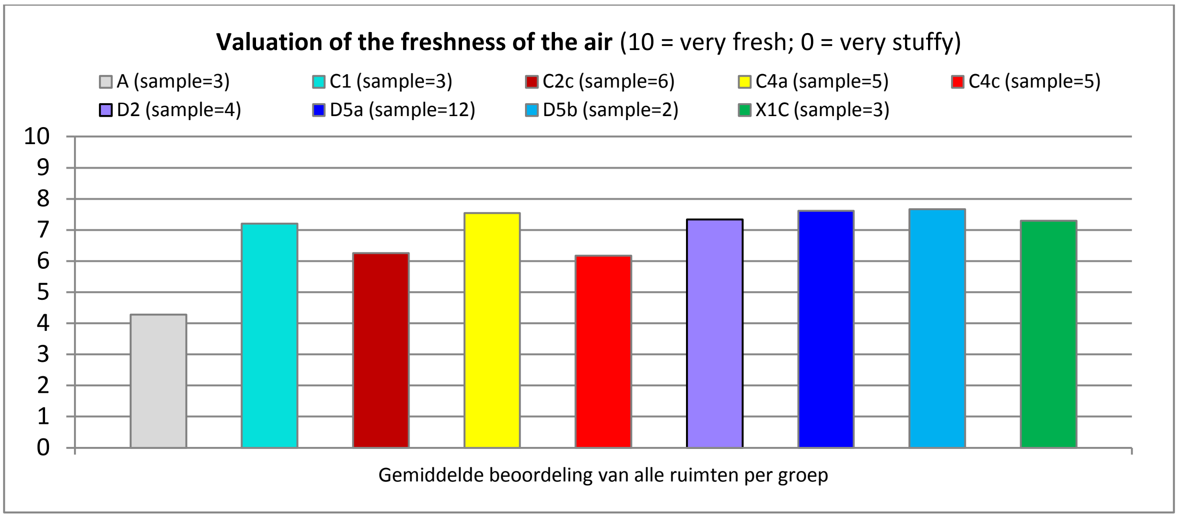


Figure 2.3.1.3 Average valuation of the freshness of the air in the dwelling's rooms

Occupants give the following assessment in terms of the presence of draughts

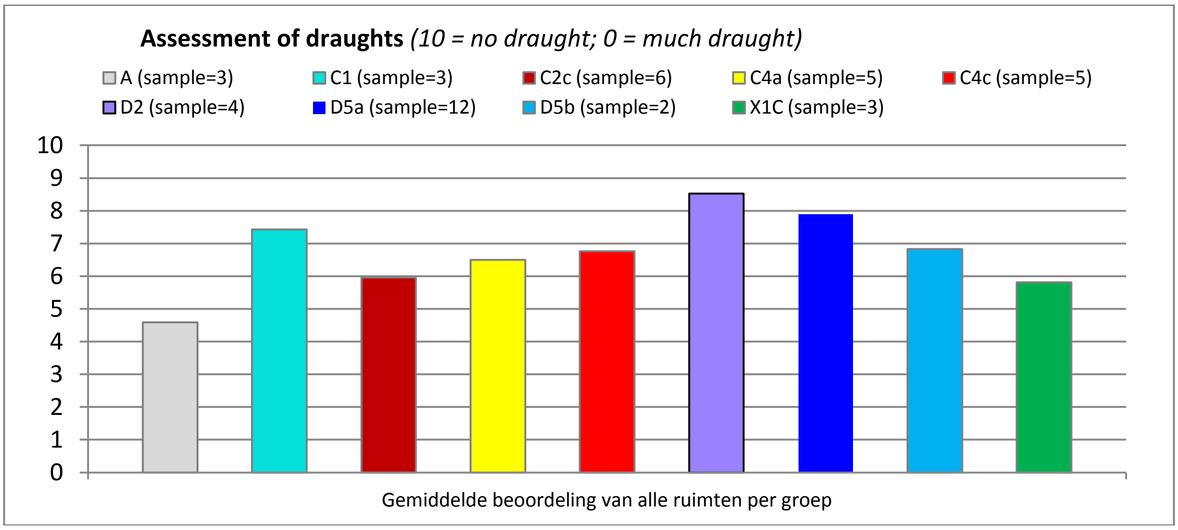


Figure 2.3.1.4 Average assessment in terms of the presence of draughts

Occupants give the following valuation in relation to the noise generated by the ventilation system

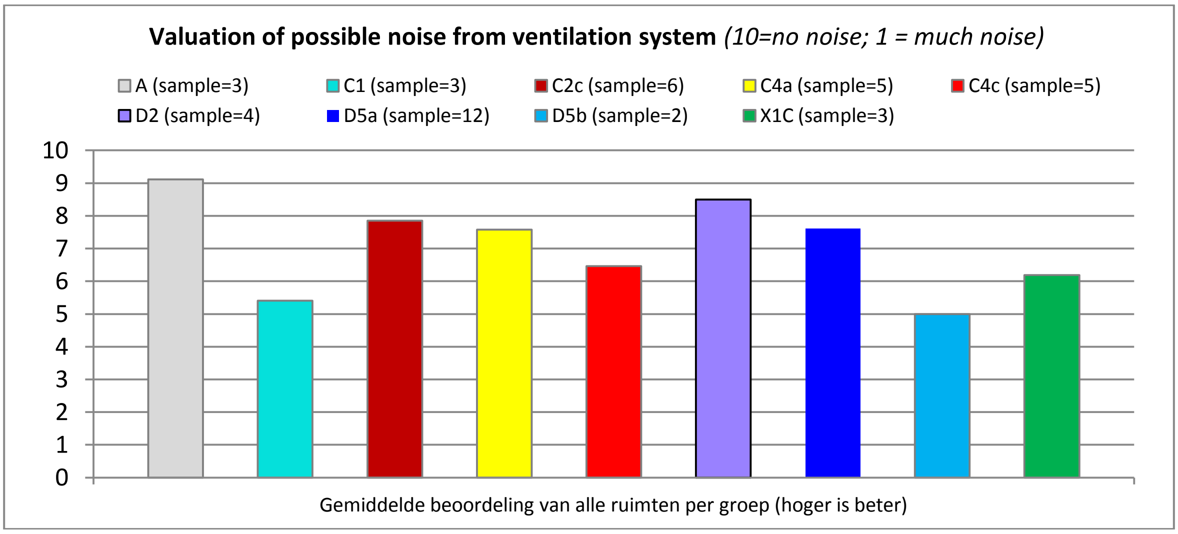


Figure 2.3.1.5 Average assessment in terms of the presence of ventilation noise

2.3.2
Use of ventilation system position switch

The position switch is used little or not at all in just one dwelling. In all other dwellings, the ventilation system position switch is used regularly. Figure 2.3.2.1 below indicates the reasons for using the position switch.

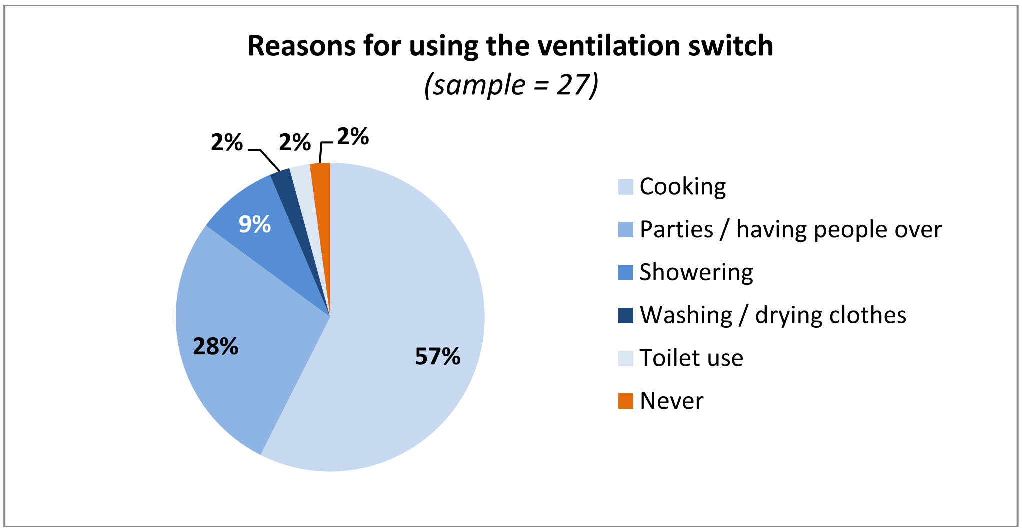


Figure 2.3.2.1 Reasons for using the ventilation-unit position switch

Cooking, the occasional party and showering are the main reasons for temporarily setting the ventilation higher.

2.3.3
Use of ventilation grilles

The figure below indicates how many dwellings leave the ventilation grilles open in the different habitable rooms (according to estimates by occupants themselves).

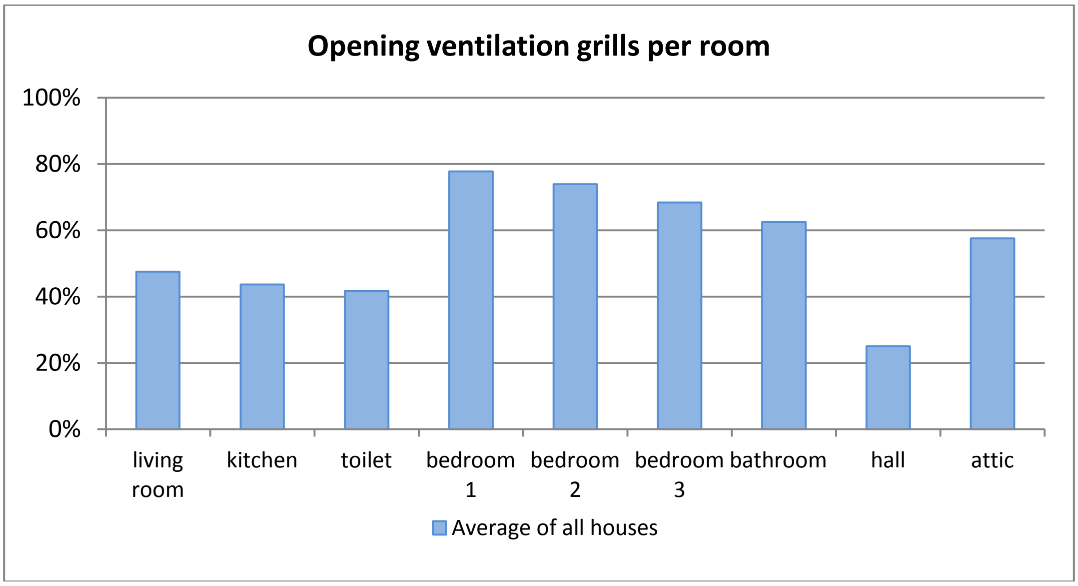


Figure 2.3.3.1 Share of habitable rooms in which ventilation grilles are left open.

According to occupants, grilles in the bedrooms are open most of the time.
But in only 50% of the dwellings surveyed the grilles in the living room and kitchen were open as well.

2.3.4
Use of extractor hood

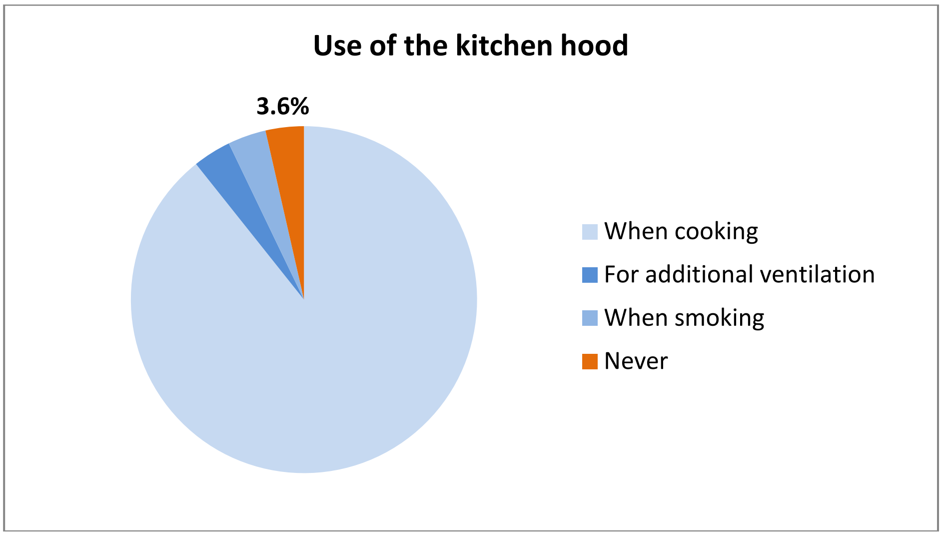


Figure 2.3.4.1 Reasons for using the extractor hood

As would be expected, occupants state that cooking is the main reason (at 90%) for using the extractor hood. A few use the extractor hood to reduce the smell from smoking.

2.3.5
Airing by opening (vent) windows.

Airing different rooms by opening (vent) windows takes place for 5 or 6 hours a day per room on average. Exceptions include the living room, with an average of 2 hours a day, and the main bedroom, with an average of nearly 12 hours a day.

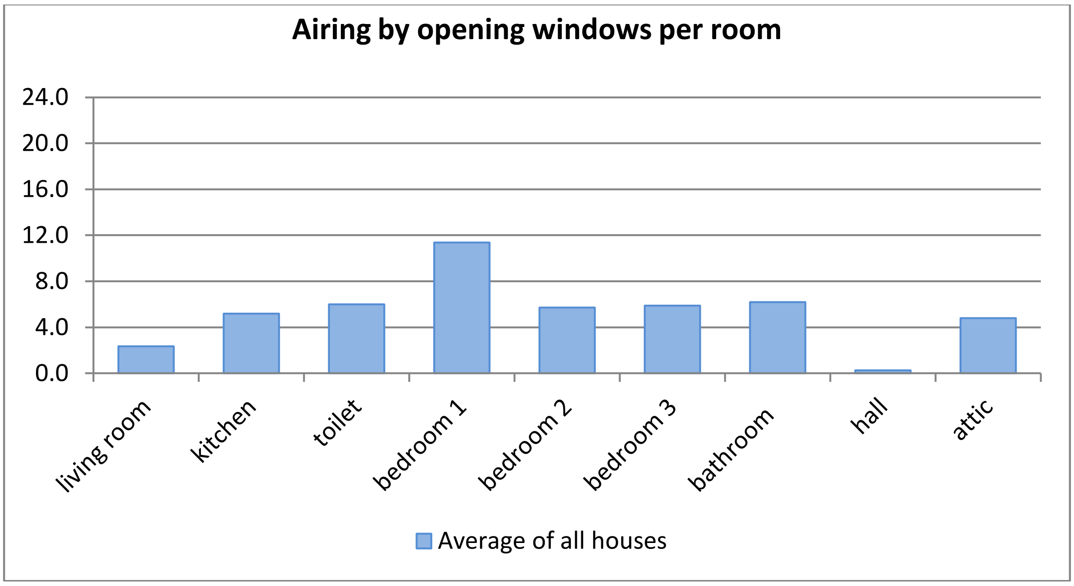


Figure 2.3.5.1 Average number of hours per day that a room is aired, according to occupant statements.

Looking at the individual answers, the periods indicated vary from 0 to 24 hours, so some people never air their house and others do 24 hours a day. The graph below gives an idea of the division in airing times among the different ventilation systems.

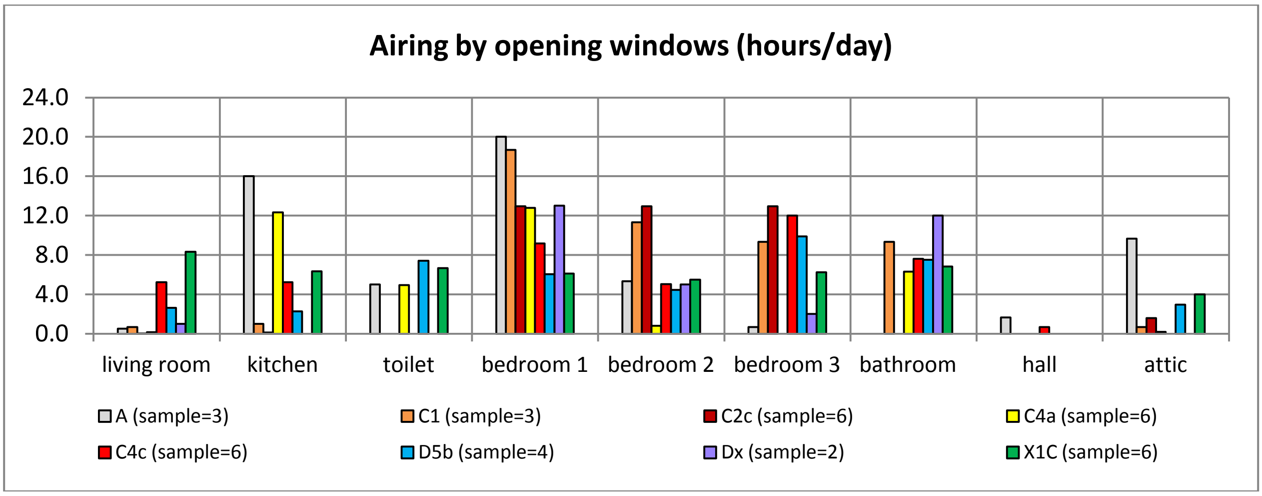


Figure 2.3.5.2 Average number of hours per ventilation system that a room is aired, according to occupant statements.

2.4
Data monitoring system

The following data-log equipment was used for the MONICAIR study:

Sensors in habitable rooms

In all habitable rooms (living rooms, bedrooms, studies, etc.):

- CO_2 sensor (NDIR type, accurate to ± 50 ppm). Measuring frequency : every 5 minutes. (This sensor was fitted as far as possible centrally in the room, at around 1.20 m above the floor, away from doors and/or windows).
- Temperature sensor (air temperature). Measuring frequency : every 5 minutes.
- Relative humidity sensor. Measuring frequency : every 5 minutes.
- Motion sensor (PIR type). Maximum measuring frequency: 1 x per ca. 7 minutes

Sensors in wet rooms

In all wet rooms (bathrooms, separate (closed) kitchen)

- Relative humidity sensor. Measuring frequency : every 5 minutes.

Sensors mechanical ventilation units

All mechanical ventilation units (MV-units, central and local heat-recovery units) are fitted with sensors that measure electricity consumption. Measuring frequency: every 10 minutes, and every change within this period.

Data logging HE combi boiler

Using the IM protocol, data is logged from the HE combi-boiler once every 6 minutes. The logged data include current gas consumption for spatial heating and for hot tap water.

Misc.

In addition to the data logging stated above, data of ventilation units with RF communication are also logged in a frequency of once every 5 minutes. This relates to systems C.4c and D.x, as well as to the decentralised heat-recovery units.

Finally, data is gathered from the KNMI weather stations closest to the various clusters of dwellings. This relates to the following data on outdoor conditions that are collected once an hour:

- Temperature
- Relative humidity
- Wind speed
- Wind direction
- Air pressure

The data and *timestamp* are collected per cluster of dwellings using RF communication and saved on a local PC. Using an FTP connection, all the data stored here are copied regularly to the central MONICAIR SQL database.

3. Data analysis

Over a period of more than a year, the data described in the previous section was collected for 62 dwellings and as many ventilation systems. This data can provide insight into the energy efficiency of the ventilation systems concerned (flowrate and energy-content of the exchanged air) and the associated performance in terms of indoor air quality (CO_2 concentrations, relative air humidity and room temperature) per room.

The data covering gas consumption for spatial heating may provide further insight into the energy usage of the dwelling in relation to the system used, air-tightness, insulation value and orientation of the dwelling and heating behaviour (realised temperature per room). The data also provides insight into a number of aspects of occupants' behaviour, including their preferred temperature for each room, control habits for mechanical ventilation units, the use of extractor hoods and hot-water consumption.

Multiple approaches can be chosen for the data analyses. Due to the available budgets and the focus of work package WP1a, the analyses in this report are limited to the energy efficiency of the different ventilation systems and associated performance in terms of indoor air quality of the heating season. The heating season is the period in which the rooms are heated and when grilles and windows are not necessarily open. To gain the clearest possible picture of the practical setting, all data will be included in the analysis, as long as data input per day is >90%. Establishing the distribution of the data is also an explicit goal of this study. This means that data of dwellings in which the ventilation unit is temporarily switched off are also included, as well as data that deviates sharply from the average values.

In work package WP1b, analyses are carried out that relate to energy consumption for spatial heating and tap water and the relation with dwelling and system quality, comfort and occupant behaviour.

3.1

Assessment of living-area indoor air quality

There is still no universally and internationally accepted method for establishing the realised indoor air quality in dwellings. However, the bodies involved are discussing the relationship between ventilation capacity and indoor air quality.

Dutch building regulations

Dutch building regulations specify minimum ventilation-capacity requirements that a dwelling must comply with, and NEN1087 also makes certain demands on how ventilation facilities are set up.

The capacity requirements are based on the surface area of the rooms: 0.7 and 0.9 $l/s/m^2$ for habitable rooms and habitable spaces, respectively, with a minimum of 7 l/s per space. Wet rooms (kitchen, bathroom, toilet) must be fitted with extraction facilities of a certain minimum capacity.

The basic assumption here is that this capacity and the set-up requirements (NEN1087) must keep CO_2 concentrations in the individual rooms below 1200 ppm CO_2, a value based on the recommendations of the National Health Council, which assumes minimum ventilation of 25 m^3/h per person.

The CO_2 concentration is an internationally generally accepted indicator or gauge of indoor air quality in which the pollution is primarily caused by the presence of humans. The literature does not define any limits for permissible excesses or deviations based on this concentration of 1200 ppm CO_2.

National Health Council

In more recent recommendations from the Dutch National Health Council to the Secretary of State of Infrastructure and the Environment state that there are developments that allow for future structural monitoring of indoor climate, including the better insulation and air-tightness of dwellings, emissions of construction materials, emissions from products in homes (flame-retardant materials, plasticizers, sensitising agents), population ageing and the associated decrease in physiological processes, changes in the local climate, etc.

These developments may lead to CO_2 concentrations becoming just one of a number of measures used to define indoor air quality.

EN 15251 Indoor Environmental Criteria for Energy Performance Calculations

EN 15251 is a European Standard implemented by authorities in the Netherlands and provides related input parameters for both the design and assessment of the energy efficiency of buildings in relation to indoor air quality, thermal comfort and acoustics. This standard is currently under review and a complementary Technical Report has also been drawn up that should serve as guideline for implementing the revised standard.

According to the preliminary prEN 15251 version, the following three methods may be used to specify the design parameters for indoor air quality in homes:

a) Method based on measured air quality
b) Method based on concentration of a certain polluting substance
c) Method based on predefined ventilation rates

With method b), CO_2 concentrations must also always be included in the assessment.

Method c) involves the *'ach'* (air change per hour) per room, but strangely enough the dwellings *overall ach* may be used, too.

For health reasons, the standard also asserts total ventilation rates of at least 4 l/s per person.

For method b), prEN 15251 also states limits for different categories of indoor air quality:

Table 3.1.1: Design CO*2* concentrations above the boundary concentrations and the associated air-volume flow rates per person

Category	Explanation	CO_2 concentration > limit concentration in ppm per person
I	Reflects high expectation level, recommended for rooms in which vulnerable people spend most of their time (the elderly, sick, very young children, etc.)	550 (10 l/s/pp)
II	Reflects normal expectation level	800 (7 l/s/pp)
III	Reflects moderate expectation level	1350 (4 l/s/pp)
IV	Reflects low expectation level – permissible for a limited period of time.	>1350

Standard average outdoor concentration is 400 ppm

Table 3.1.2: Draft CO*2* concentrations habitable rooms for generally accepted standard CO*2* emissions of 20 l/h/pp for non-bedrooms and 13.6 l/h/pp for bedrooms

Category	Draft ΔCO_2 concentration for habitable rooms (not bedrooms) in ppm above outdoor concentration	Draft ΔCO_2 concentration for bedrooms in ppm above outdoor concentration
I	550 (10 l/s/pp)	380
II	800 (7 l/s/pp)	550
III	1350 (4 l/s/pp)	950
IV	> 1350	950

Unfortunately the prEN 15251 does not provide any limits for the deviations or excesses that are permissible to allow classification in one of the classes.

However, the informative Annex G of the draft version of the TR 15251 does provide some reference points for this evaluation. Under the heading '*Recommended criteria for acceptable deviations*' the following text is proposed: "to be classified in the indicated category, the annual upper limit may not be exceeded for more than 3% (or 6%) of the time occupants are present".

VLA methodology

In the Netherlands, the Dutch Association of Suppliers of Air Handling Equipment (Vereniging Leveranciers Luchttechnische Apparaten, or the VLA) has developed a systematic together with Peutz, Nieman Raadgevend Ingenieurs, Cauberg-Huygen Raadgevend Ingenieurs and TNO to determine the energy consumption (saving) of ventilation systems, so Declarations of Equivalence can be issued. This refers to a simulation model that not only looks at the energy consumption, but naturally also considers the performance of the ventilation system in terms of indoor air quality.

To assess air quality, the exposure to CO_2 concentrations is defined for each occupant, totalled across the different habitable rooms. The upper limit for CO_2 concentration is assumed to be 800 ppm above outdoor air concentrations (which are estimated at 400 ppm). The test looks at both the degree of excess (how much higher the concentration is than 1200 ppm) and the duration of the excess (how long the period is that the CO_2 is above 1200 ppm). The product of both values provides an Air Quality Index (AQI) number.

In terms of a formula, AQI for person i :

$$\mathrm{AQI}_i \quad = \quad \sum (C_{\mathrm{detected}} \; - 1200 \,) \, / \, 1000 \;\; * \;\; time_{\mathrm{detected}} \quad [\mathrm{kppmh}]$$

In that

AQI_i : Air Quality Index of person i, in kppmh
C_{detected} : The detected CO_2-concentration value in a habitable room
1200 : The sum of outdoor concentrations (400 ppm) plus limit concentrations (800 ppm)
1000 : Figure needed for conversion from ppm to kppm
$time_{\mathrm{detected}}$: The period of time of excess CO_2 levels

The AQI, or the excess CO_2 level is thus expressed in kilo-ppm-hours [kppmh] per person. The upper limits to be applied to the AQI are still a hot topic of discussion. So a definitive upper limit has not yet been defined, let alone any permitted deviations from the yet-to-be-agreed limit. If one were to use the LVI (Low Ventilation Index) of 0.005 from previous simulation programmes and demand similar air quality for the new simulation model, then that would correspond with an AQI of 30 kppmh. To what degree these theoretically defined values are representative of reality is yet to be established by the results of MONICAIR WP1a.

3.2
Indicator of living-area indoor air quality

Based on the considerations in section 3.1, this study applies the following method to determine the performance in terms of indoor air quality in habitable rooms:

a) Determine for each habitable room in the dwelling the average number of hours per day during the heating season in which CO_2 concentrations exceed the upper limit of 1200 ppm (unit: hours/day). This upper limit corresponds with the recommendations of the Dutch Health Council that is used as the starting point for Dutch building regulations. This upper limit also corresponds with class II of prEN 15251, fitting 'normal level of expectation' in terms of indoor air quality.

b) Determine for each habitable room in the dwelling the average concentration with which the upper limit of 1200 ppm CO_2 is exceeded per hour during the heating season (unit: ppm)

c) Calculate total CO2- excess doses during the heating season in kppmh for each habitable room in the dwelling, by multiplying together the outcome of a) and b) and then multiplying this number by the number of heating days (212) and dividing this by 1000 to convert the final outcome from ppmh to kppmh.

d) Add together the CO2- excess doses of all habitable rooms in the dwelling and divide this number by the number of occupants of the dwelling concerned to determine the CO2- excess doses in kppmh per person during the heating season.

Note 1.
The calculation under a) and b) are made per period of 5 minutes (= log frequency) and are then totalised into hours per day or excess levels per hour.

Note 2.
The proposed calculation under d) for determining CO2- excess doses per person will be lower than is the case in reality as this method does not take account of the fact that more than one person can be exposed to the same CO2- excess doses in a room (main bedroom).

In addition to CO_2 concentrations, the relative humidity of the various rooms is also considered. Also calculated is how many hours a day RH is > 70% on average and how many hours a day it is below 30% on average.

3.3
Indicator of wet-room indoor air quality

Because occupants are only present in wet rooms for a limited time (bathroom, toilet, separate kitchen), the CO2- excess doses in these rooms will be limited. In terms of the analysis of air quality, the key focus point is relative humidity. The comfort bandwidth in this study uses an upper limit of 70% and a lower limit of 30% relative humidity.
For each room it is assessed how many hours a day relative humidity exceeds 70% and how many hours a day relative humidity is below 30%.

As a result of cooking activities, it is expected that the kitchen will show higher concentrations of polluting substances during the preparation of meals, with CO_2 concentrations and RGH values also rising.
Only the latter of these can be demonstrated in this study.

3.4
Indicator for energy efficiency

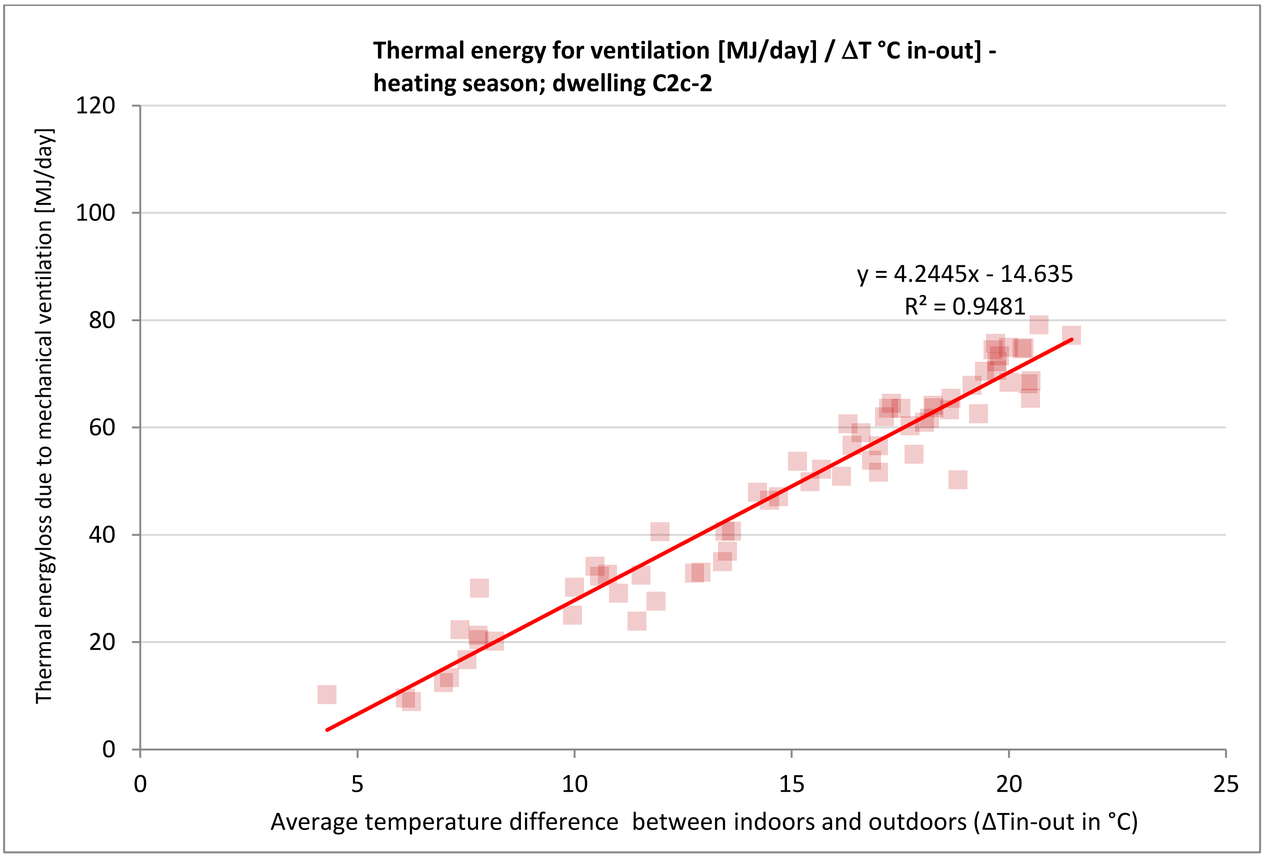
In this study, the energy efficiency of a mechanical ventilation system is based on the difference in energy content between the actual volumes of air exchanged by the ventilation system. If the ventilation system uses heat recovery, then the energy content of the air volumes exchanged via the heat-recovery unit are corrected using the EN13141-7/8 yield of the heat-recovery unit. This applies the following method:

e) Determine per hour the total average ventilation rates of all mechanical ventilation units in the dwelling (excl. extractor hood).
f) Determine the hourly average of the indoor temperature and indoor humidity (obtained by determining the hourly average of all habitable rooms and the hourly average of all bedrooms, and then adding these together and dividing by 2).
g) Determine the hourly average of the outdoor temperature, outdoor humidity and air pressure using data from the closest KNMI weather station.
h) Calculate per hour the difference in energy content of the exchanged air using data from e), f) and g) and in relation to the average temperature difference between indoors and outdoors (ΔTin-out) over the hour concerned. For ventilation systems or units that use heat recovery the calculated energy content is corrected on the basis of the efficiency of the heat-recovery unit (related to the hourly average ventilation rates concerned), determined in line with EN13141-7/8.
i) Calculate per day the total energy content of the exchanged air in relation to the daily average of ΔTin-out, and convert this relationship to a mathematical linear function.
j) Calculate the total primary energy consumption for mechanical ventilation for an average heating season as follows:
    - Determine the thermal energy exchange from mechanical ventilation per day with a ΔTin-out of 13°C (this is applied as an average ΔTin-out for a Dutch heating season).
    - Multiply this by 212 days (duration of heating season).

- Divide this by the average system efficiency of an HE heating system, i.e. 85% (system with condensing boiler and low distribution losses).
- Add to this the total electricity consumption of all ventilation units during the heating season, after converting this to primary energy (divide by 0.4).

k) Divide the outcome of j) by the total heated area of the dwelling concerned to determine the average primary energy consumption per m^2 living space for the ventilation system concerned.

Figure 3.4.1.
Example of the data analysis in line with section 3.4 steps e) to i).



Each point in the graph represents a day in which thermal energy loss from mechanical ventilation for dwelling no. 6 has been calculated in relation to the average temperature difference of that day between outdoors and indoors (steps *e* to *i*). The function of the trend line ($y = 4.2445x - 14.635$) shows the relationship between the daily thermal energy loss and the temperature difference between indoors and outdoors.
Step j): with a ΔTin-out of 13°C, the thermal energy loss (fill in 13 in the comparison) 40.54 MJ/day, and so for a whole heating season 212 x 38.54 = 8595 MJ. A heating system with an assumed system efficiency of 85% must supply this thermal energy, which means that 8595/0.85 = 10,118 MJ of primary energy is needed here per average heating season. The average electricity consumption of the mechanical ventilation of this dwelling amounts to 19.53 watts. For a heating season of 212 days, this is 19.53 x 24 x 212 /1000 = 99.37 kWh. Converted to primary energy, this is 99.37 / 0.4 = 248 kWh or 894 MJ per heating season.

Total primary energy consumption for the mechanical ventilation therefore amounts to 10,118 + 894 = 11,012 MJ per heating season.

The dwelling has 96.12 m2 of heated area, so the primary energy consumption of the ventilation system in this home amounts to 11,012 / 96.12 = 114.5 MJ/m2

These calculations have been carried out for all ventilation systems in all dwellings. This makes it possible to gain a relatively reliable indication of the energy efficiency of these ventilation systems.

Note:
The energy losses occurring as a result of cross-ventilation and infiltration are not included in the calculations above.

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4. Results

4.1 Ventilation rates and control

4.1.1

Average ventilation rates per dwelling

Figure 4.1.1.1 shows the average mechanical ventilation rates occurring per dwelling. All systems are programmed in line with Dutch building regulations and thus realise 0.9 l/s or 3.2 m^3/h per m2 of habitable room, at least in their highest setting. Because figure 4.1.1.1 below relates to the total heated surface area of the dwelling and not just of the habitable rooms, these figures must be corrected, before comparison, using the ratio between the area of all habitable rooms and the total heated area of the dwelling. The correction figure used here is 0.70, or an average of 70% of the total heated area relating to habitable rooms. This means that in the graph below a value of 3.2 * 0.70 = 2.25 $m^3/h/m^2$ corresponds roughly with the capacity that should be feasible according to the building regulations.

Figure 4.1.1.1 shows that the average ventilation rates do not correspond in any dwelling with the capacity prescribed in the building regulations. This is to be expected as no single system is continually set to position 3.

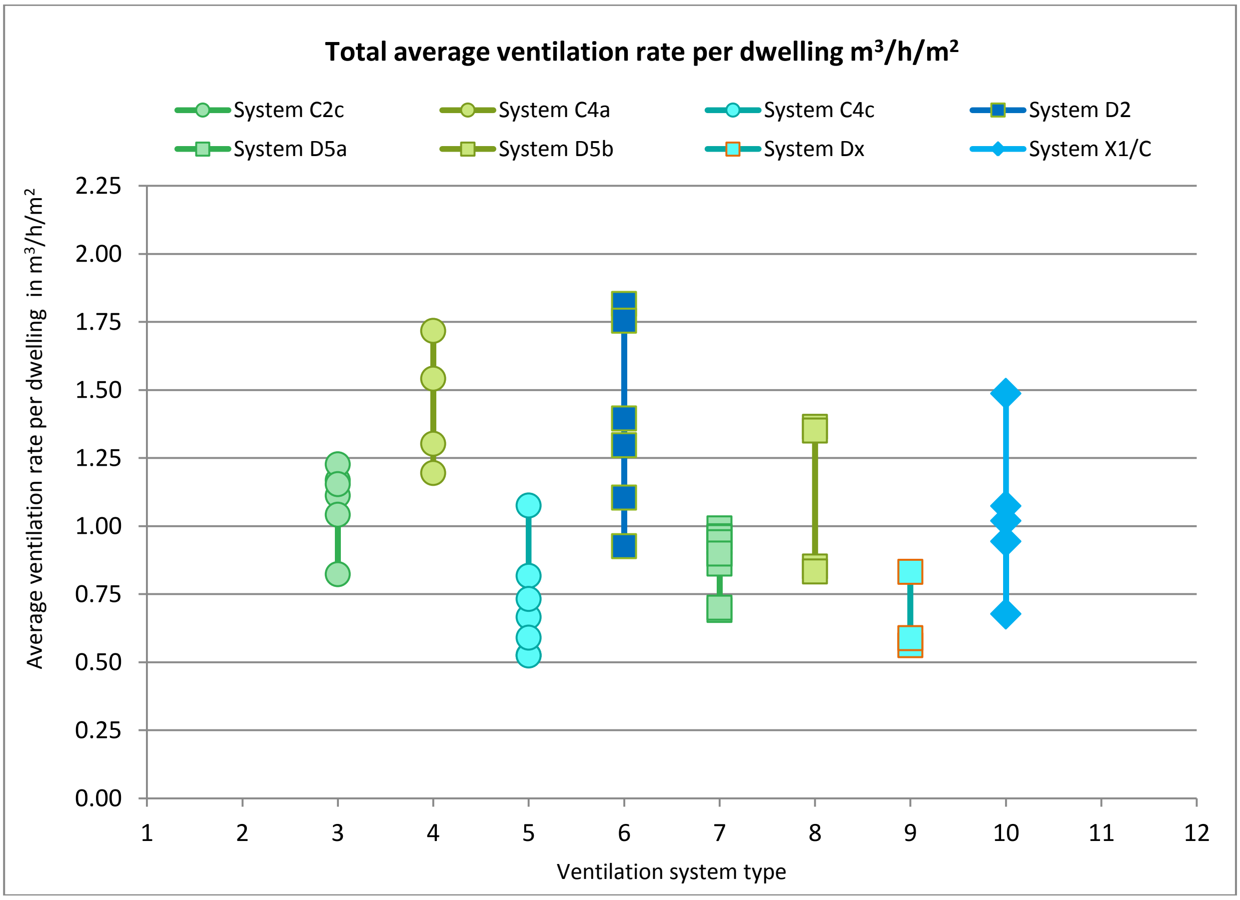


Figure 4.1.1.1: Average mechanical ventilation rates per dwelling in m3/h per m2 heated area

Just three dwellings are at an average of about 70–80% of the capacity in the building regulations. These also happen to be the few homes in which occupants show active switching behaviour.
On average for all systems, ventilation rates are around 1 m^3/h/m^2, with related ventilation rates per person varying from 40 to ca. 50 m^3/h/pp. This 1 m^3/h per m^2 heated area roughly corresponds with ventilation flow rate of 0.40 l/s/m^2 in habitable rooms, corresponding with ca. 45% of building-regulation requirements.
The 40 to ca. 50 m^3/h/pp means that in theory all ventilation systems should have enough ventilation capacity to prevent CO2- excess doses in habitable rooms. That this is not the case comes from the fact that this air exchange does not take place in the habitable rooms in which it is actually needed.

Figure 4.1.1.2 shows the average values for the mechanical ventilation rates and related CO2- excess doses per group of ventilation systems.

Ventilation system	Average mech. ventilation rates			Excess CO_2 level	
	[m^3/h/m^2]	Stndrd dev. [m^3/h/m^2]	[m3/h/pp]	[kppmh/pp/ht.ssn]	Stnrd dev. [kppmh/pp/ht.ssn]
System A	n/a	n/a	n/a	442	438
System C1	[1]	[1]	[1]	345	276
System C2c	1.09	0.14	41.9	244	216
System C4a	1.44	0.24	41.1	271	389
System C4c (with mech.ext. habitable rooms)	0.71	0.12	48.7	72	78
System D2	1.38	0.35	51.8	68 [2]	32
System D5a	0.89	0.11	51.9	106 [2]	156
System D5b	1.10	0.30	39.5	183 [2]	199
System Dx	0.75	0.22	38.8	76	32
System X1/C	1.04	0.29	37.3	175 [2]	139
System X1/A	?	?	?	167 [2]	124

[1.] Flow rates could not be measured for all dwellings in this group.

[2.] Values are not corrected for incorrect use (when switching off and/or adjusting) of the ventilation system due to draughts and/or noise.

Figure 4.1.1.2: Average mechanical ventilation rates in m3/h per m^2 heated area and CO2- excess doses in kppmh per person per heating season, per group of ventilation systems.

Strikingly in this table the systems with a CO_2 sensor in 1 or two zones (systems C4a and D5a) have higher CO2- excess doses than the same systems without CO_2 sensors (systems C2c and D2), (see also section 4.1.3).

4.1.2
Operation of ventilation system by occupant

Operating ventilation units

Aside from the use of an extractor hood during cooking, most occupants show little or no reactive ventilation behaviour. With the exception of a few families, most homes with a centrally-located manually-operated mechanical ventilation unit leave the 3-position switch on setting 1. For most dwellings, the mechanical ventilation rates of setting 1 are more or less representative of average realised ventilation rates. The temporary higher rates that some occupants switch on when showering only have a limited effect on this average.

There are no guidelines for minimum target rates. The ventilation rate in position 1 is the rate that arises spontaneously, where the flow rate in position 3 is programmed in line with the building regulations. This is the flow rate arising more or less coincidentally as a result of the combination of the manufacturer's random speed reduction from position 1 versus position 3 and the resistance in the duct system. The measurements suggest that minimum flow rates can vary from 0.4 to over 1.0 m^3/h per square meter of heated surface area, which corresponds with ca. 0.16 to 0.40 l/s per square meter of living space.

Illustrations of 3-position switch controls

The figures below provide an illustration of the degree to which the ventilation systems are operated by occupants. This only relates to manually operated ventilation systems, or the systems with only a 3-position switch (systems C1, C2c, D2). The figure shows the average hourly flow rates for the same day during the heating season. Each hourly average is shown using a semi-transparent marking, with the darker the marking, the more often this hourly average occurs. The unbroken line represents the arithmetical average over all selected days of the week during the heating season.

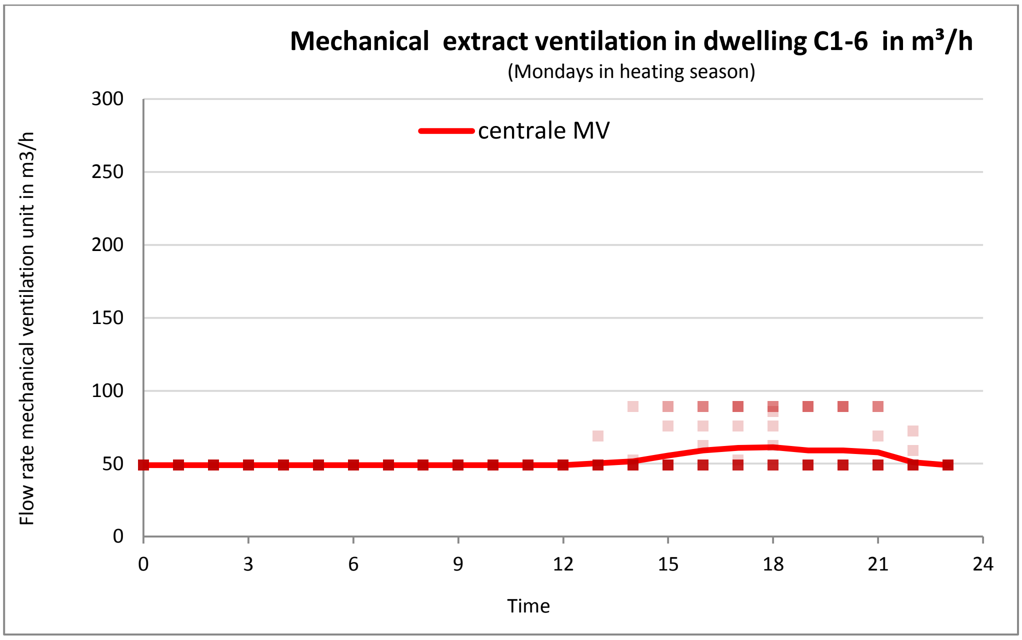


Figure 4.1.2.1 Illustration of operation of ventilation system C1 by occupant

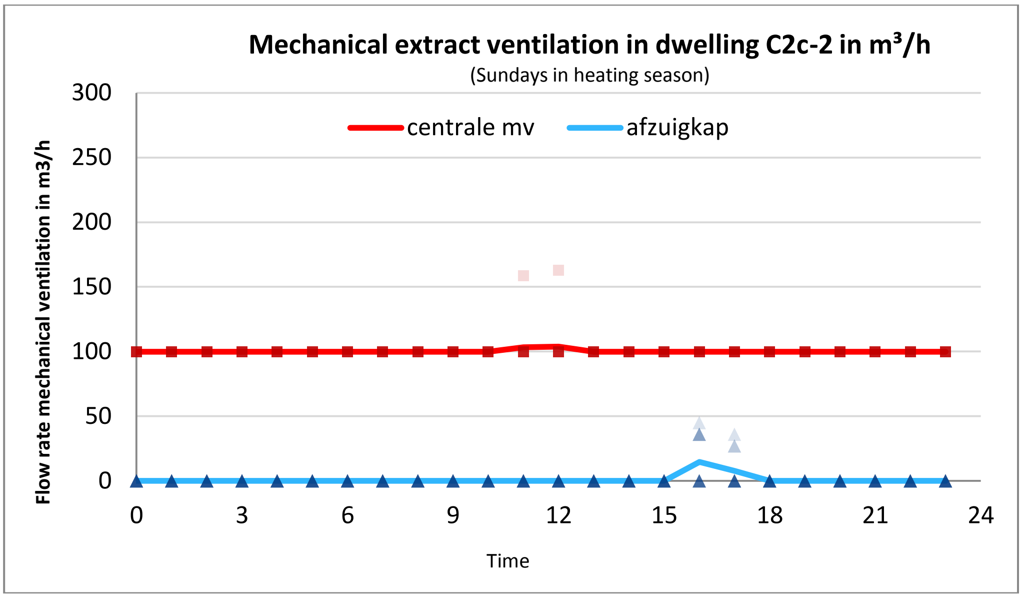


Figure 4.1.2.2 Illustration of operation of ventilation system C2c by occupant

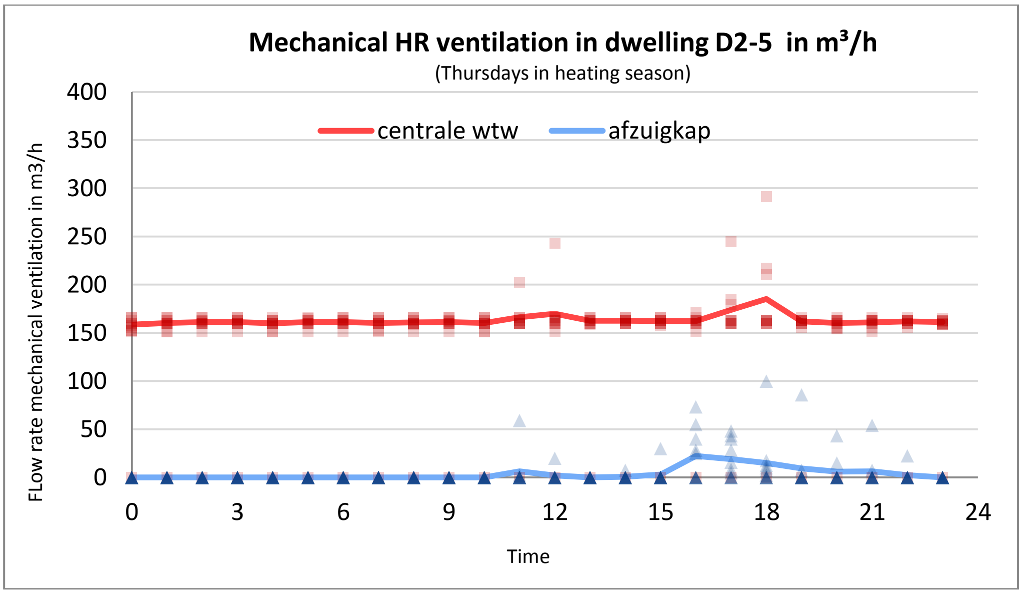


Figure 4.1.2.3 Illustration of operation of ventilation system D2 by occupant

<u>Operation of ventilation grilles</u>

Most families show little reactive behaviour in terms of operating the 3-position switch.

High CO_2 concentrations do not lead to desired behaviour by occupants. However, most occupants show a certain more or less fixed pattern when it comes to operating ventilation components. This applies not only to extractor hoods or for the 3-position switch when showering, but also to the use of ventilation grilles and/or vent windows. From intake interviews it appears that the supply grilles in the bedrooms are used actively by most occupants based on a habitual pattern. Also, based on simulations carried out by TNO (work package WP2a) in which model simulations attempted to reproduce CO_2 values, it appears that CO2- excess doses in bedrooms can only be reproduced if ventilation grilles in the bedrooms are left open. In terms of living rooms, there is generally a less active pattern of use of ventilation grilles.

Incorrect operation

Incorrect operation is understood to include operating actions not intended to be carried out and that negatively affects the functionality of the ventilation system. This includes (temporarily) switching off a fan or complete ventilation unit or (partially) closing an air supply or exhaust valve.

Such operational actions are only observed in systems with both mechanical supply and mechanical extraction facilities. The reasons for this behaviour include problems with draughts and/or noise. This incorrect behaviour is the main explanation for the fact that some of the dwellings with ventilation systems that include a mechanical component in the habitable rooms show relatively high CO2- excess doses .

4.1.3

CO_2 controlled ventilation system

A number of ventilation systems not only use the common manual operation (position switch), but also have a CO_2 sensor that regulates ventilation flows (systems C4a, C4c, D5a, D5b, Dx and X1/C and X1/A). These systems can be further distinguished on the basis of whether or not there is a direct link between the habitable rooms and the CO_2 sensor and/or flow rate control.

Systems without a direct link between the habitable room and the CO_2sensor and/or flow rate control

Ventilation systems that use both manually operation (position switch) and a CO_2 sensor that regulates ventilation flows in general show more active shifting in ventilation flows. See figures below.

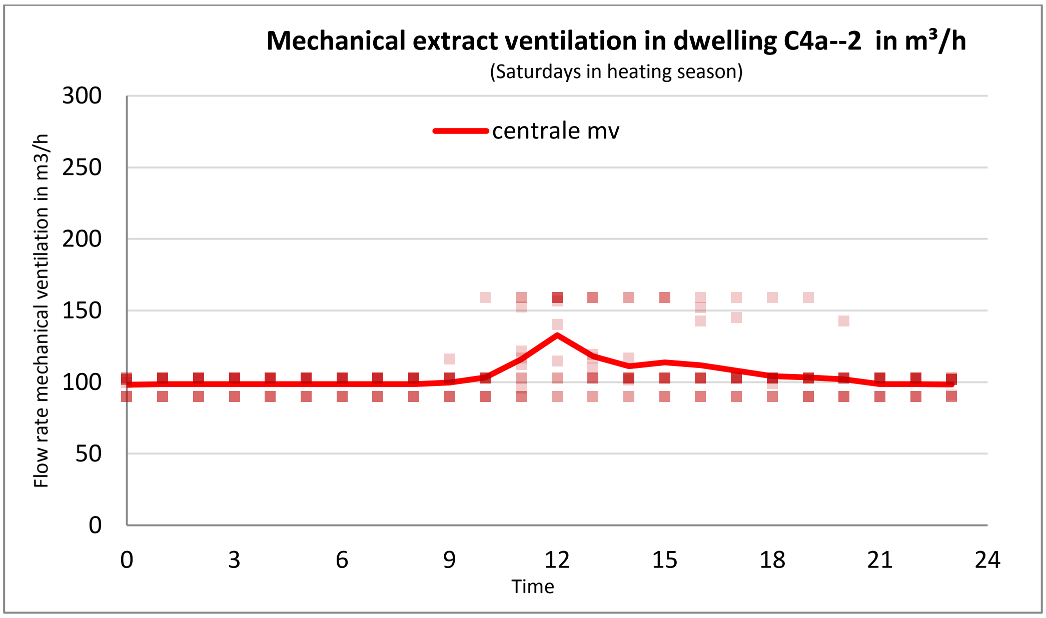


Figure 4.1.3.1 Illustration of automatic control of ventilation system C4a.

Despite slightly more active switching behaviour for systems C4a and D5a (see also figure on following page), the average CO2- excess doses of these systems is no less than comparable systems without CO_2 control (C2c and D2).

For system C4a, CO2- excess doses in the living room in particular are higher, and for system D5a the bedrooms show higher CO2- excess doses . Possible explanations for this include the following. For system C4a the sensor is positioned in the living room, but the mechanical (CO_2-controlled) air extraction is positioned in the (separate) kitchen. The air extracted from the kitchen therefore does not come sufficiently from the living room.
For system D5b, a CO_2 sensor is positioned in the connecting space (hallway) between the bedrooms. As this CO_2 sensor probably measures acceptable values (depending on the sensor's settings), this means that the air collected from the hallway is not representative for air quality in the different bedrooms, or the sensor settings are incorrect. Also both causes could apply at the same time. Where the air extracted from the extraction valve in the bathroom ultimately comes from, depends on the position of the bedroom doors and the ease with which air can be transported up from the ground floor. Air is transported via the path of least resistance and that is the air that is measured by the CO_2 sensor in the hallway. The room from which this air originates can thus change throughout the day.

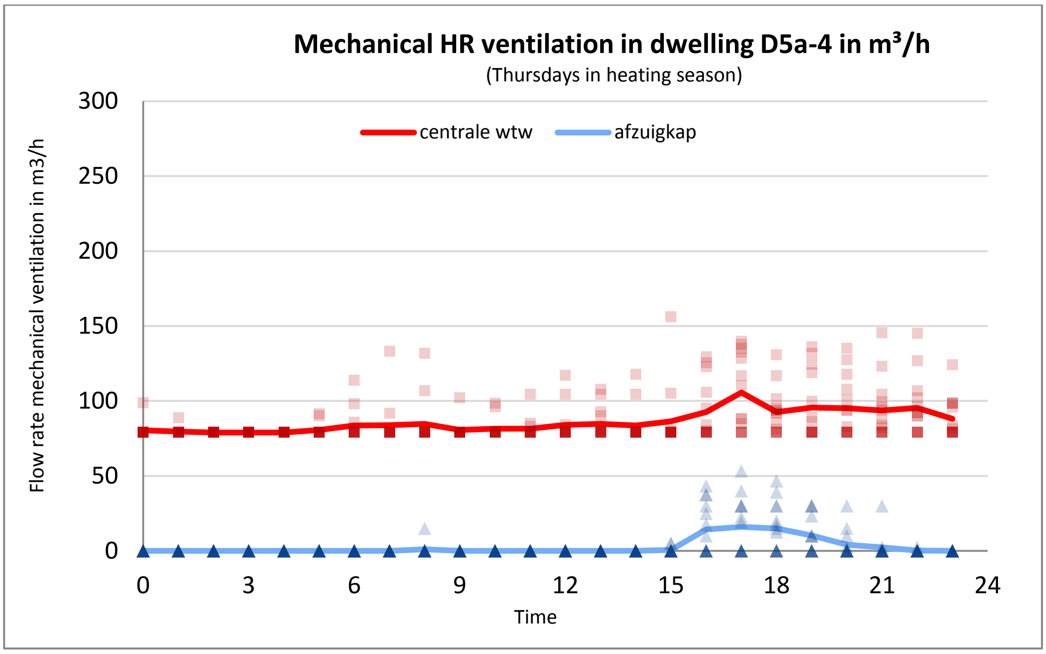


Figure 4.1.3.2 Illustration of automatic control of ventilation system D5a.

Systems with a direct link between the habitable room and the CO_2sensor and/or flow rate control

For ventilation systems C4c and Dx, but also for systems with decentralised heat recovery (D5b and X1/C and X1/A), the CO_2 measurements are carried out in a specific habitable room and the related CO_2 control of the ventilation flow relates to the mechanical flow of that specific room.

The illustrations of the flow rate control of systems Dx and X1/C (see figures on next page) show very active behaviour. When CO_2 measurements specific to these habitable rooms are carried out correctly and the revised flow actually arrives in that room, this increases the effectiveness of the ventilation and reduces the amount of CO2- excess doses .

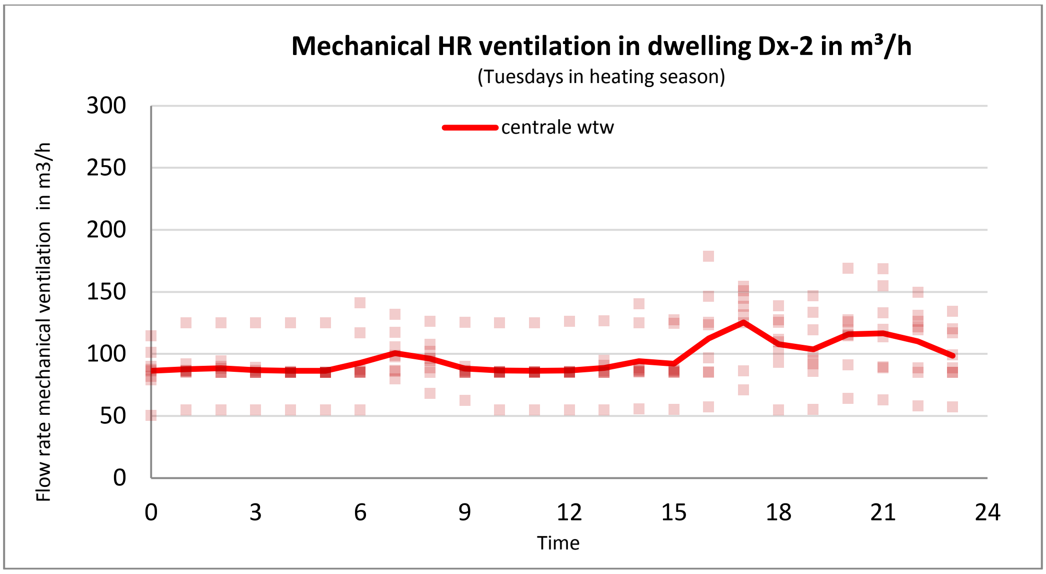


Figure 4.1.3.3 Illustration of automatic control of ventilation system Dx.

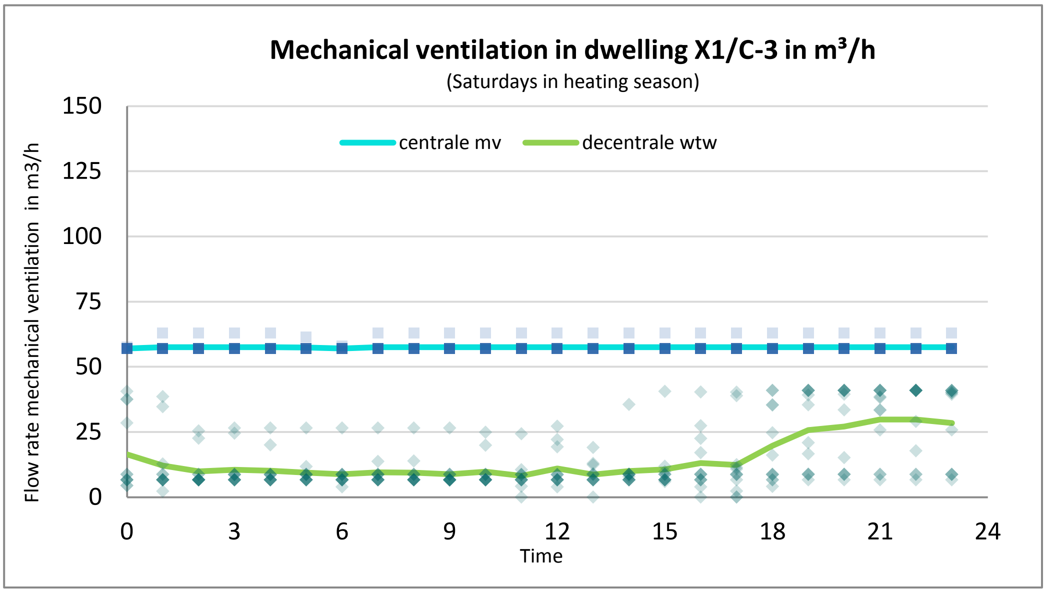


Figure 4.1.3.4 Illustration of automatic control of ventilation system X1/C.

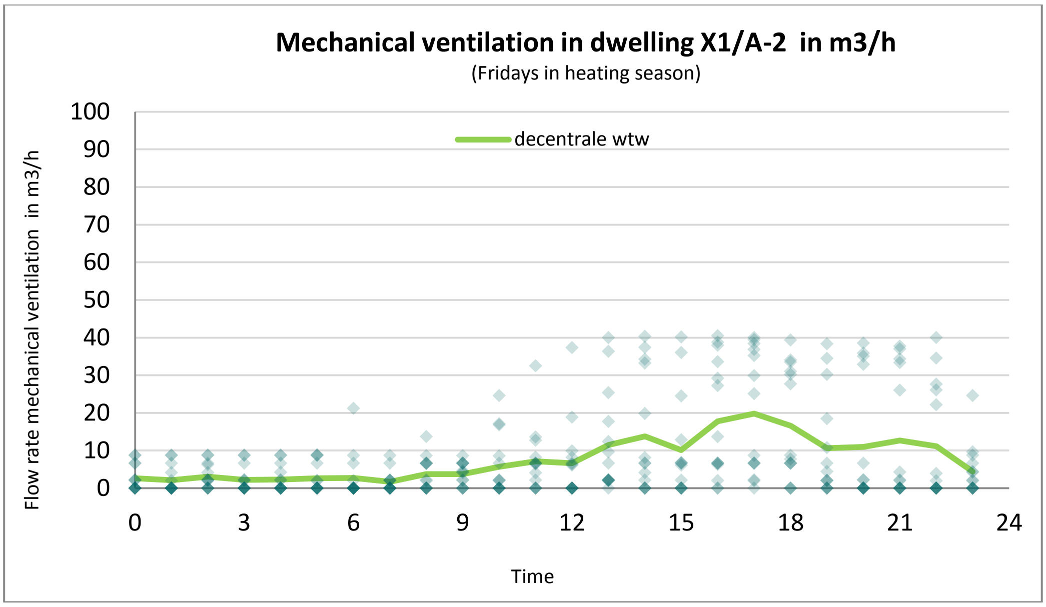


Figure 4.1.3.5 Illustration of automatic control of ventilation system X1/A.

That a CO_2-regulated ventilation control per habitable room does not by definition reduce CO2- excess doses to minimum values is illustrated in the two figures on the following page. When CO_2 measurements are not representative of the habitable room concerned and the subsequent mechanical air flows do not arrive correctly in the habitable room concerned, excess CO_2 levels will persist. Possible causes of this might include:

For systems C4c and Dx :

- location of extraction point (too close to door or ventilation grille (system C4c), so habitable room is not properly aired);
- relative position of dividing doors (i.e. their position relative to each other)

Systems with decentralised heat recovery:

- curtains hanging over the decentralised heat-recovery unit and that can hamper CO_2 sensors and air refreshment.
- gaps and other unintended openings in the façade (adjacent to window and door frames) may cause leakage of air over the CO_2 sensor, resulting in a CO_2 measurement that is not representative for the habitable room concerned.

Two good examples:

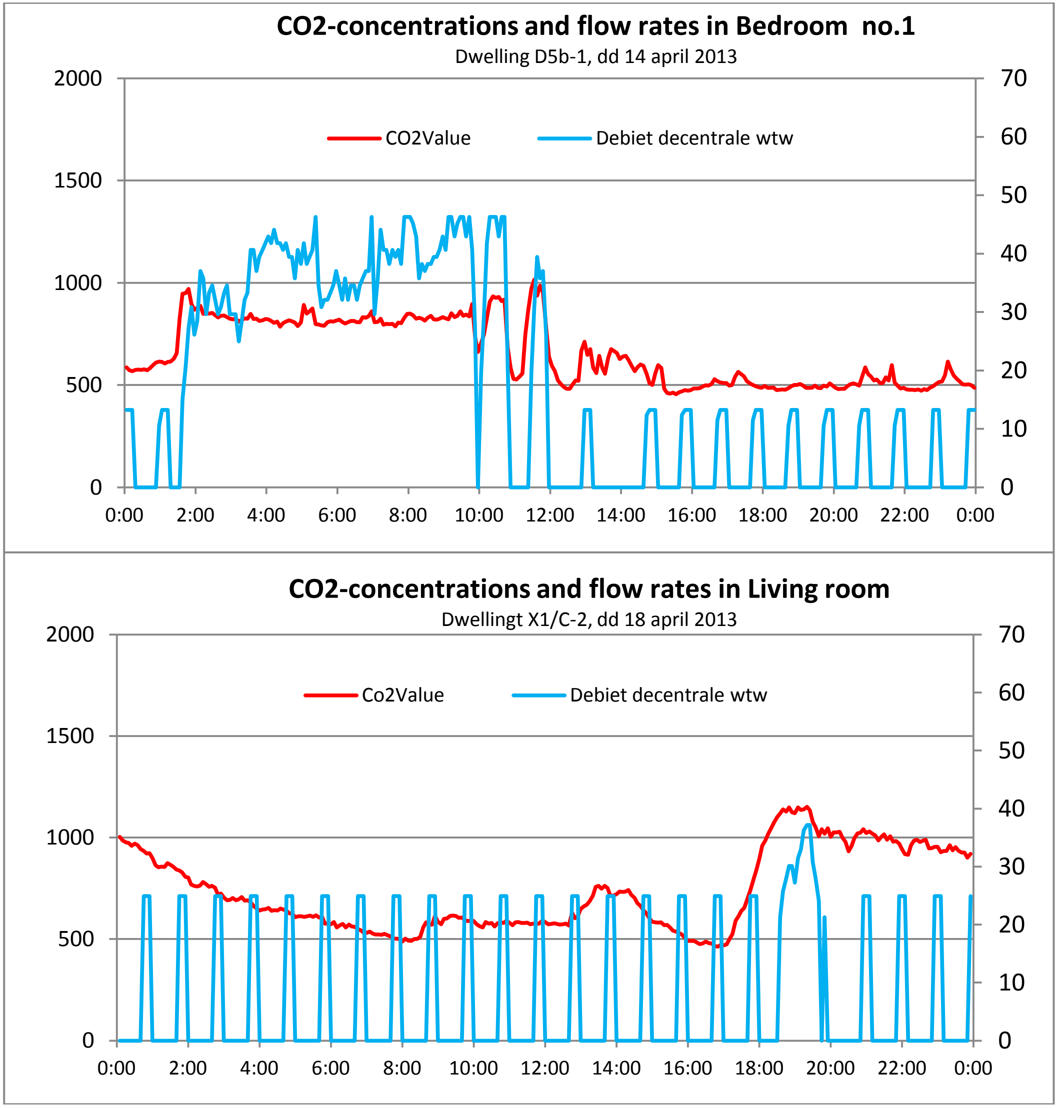


Figure 4.1.3.6 Examples of properly functioning CO2-controlled flow control per habitable room.

For that matter, even with a less efficient flow-through of air in the habitable room, CO_2 concentrations will fall
as a result of the partial pressure differences in CO_2 concentrations between the present indoor air and the fresh outdoor air supplied. However, this mechanism does not work as fast and is less effective than the method that also flushes air through the habitable room.

Two less good examples:

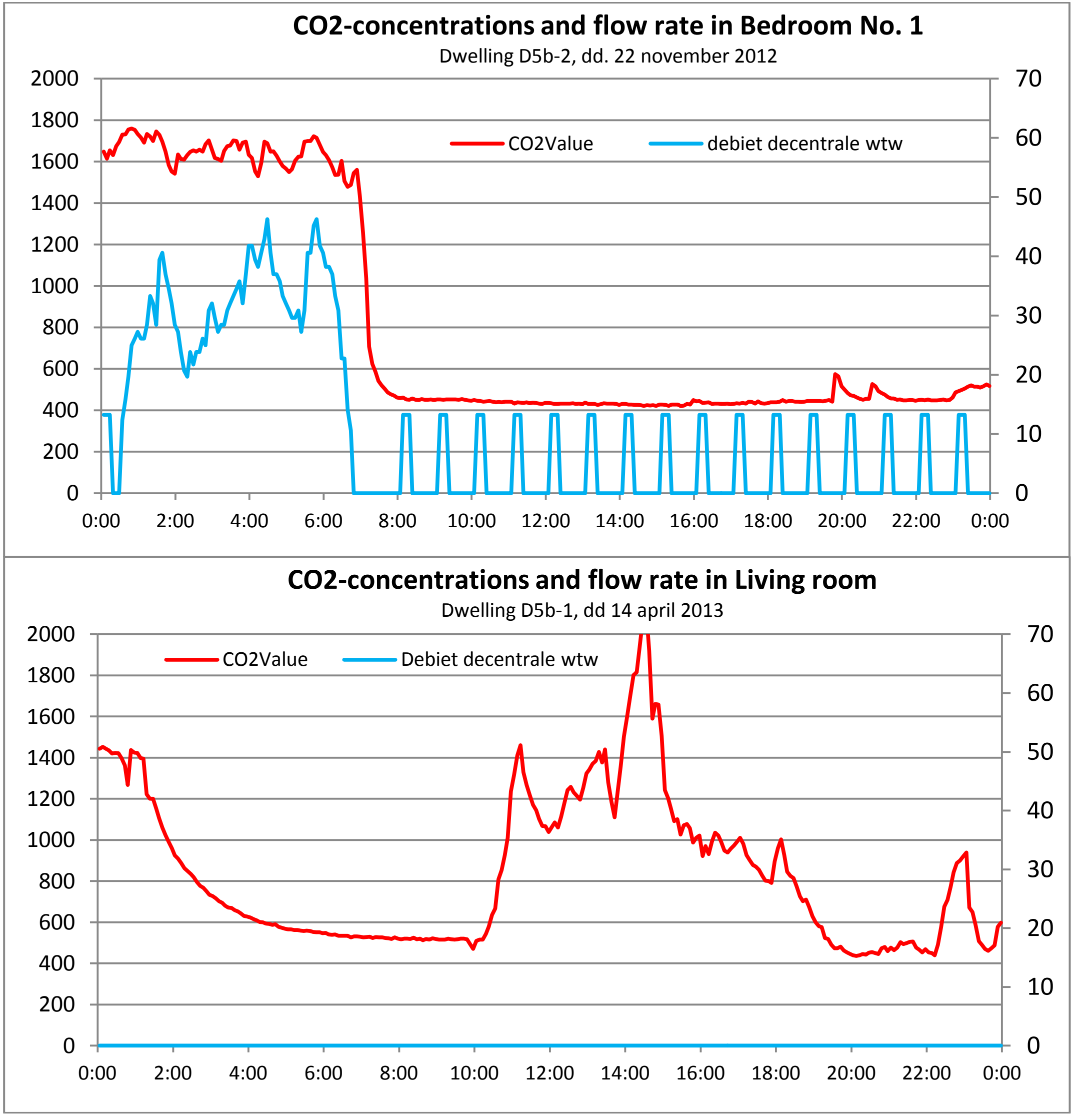


Figure 4.1.3.7 Examples of less properly functioning CO2-controled flow rate per habitable room.
(Note: in the last example, the decentralised heat-recovery unit is switched off by the occupants)

Ventilation systems with a CO_2 sensor in every habitable room, and with a linked mechanical component for the habitable room concerned, can prevent CO2- excess doses in habitable rooms with a high degree of ventilation effectiveness. However, this is on the condition that systems are optimised for the following aspects:

- CO_2 measurement is always representative of the habitable room concerned
- Air refreshment is preferably based on flushing air through the room
- The system generates little or no noise
- The system causes no draughts

4.2 Results related to CO2- excess doses during heating season

4.2.1
Illustration of excess CO_2 levels per ventilation system

To gain greater insight into the development of CO_2 concentrations in habitable rooms for different ventilation systems, graphs are shown below of CO_2 concentrations per ventilation system for a few habitable rooms over a number of random days during the heating season. The blue horizontal line is the upper limit of 1200 ppm CO_2.

System A, Dwelling A-2 | Number of occupants: 2

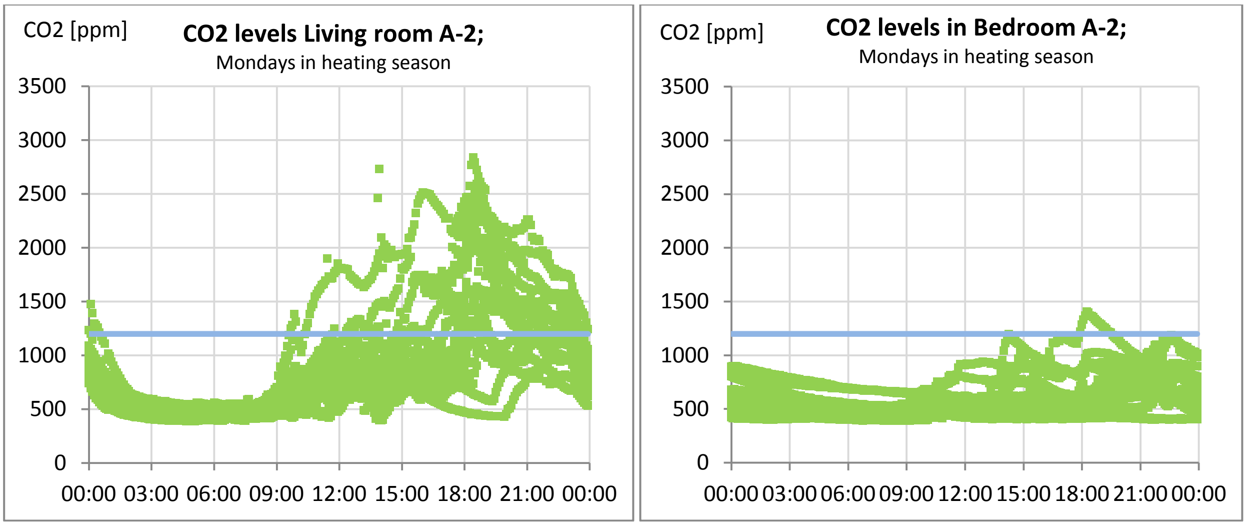


Figure 4.2.1.1 Illustrations of excess CO2 levels in the living room and bedroom of system A.

Note: In the intake interview, the occupant indicated that both the ventilation grille and the vent window are permanently open in the main bedroom. In the living room, grilles and windows are mostly closed, according to the occupant.

System C.1, Dwelling C1-4 | Number of occupants: 4

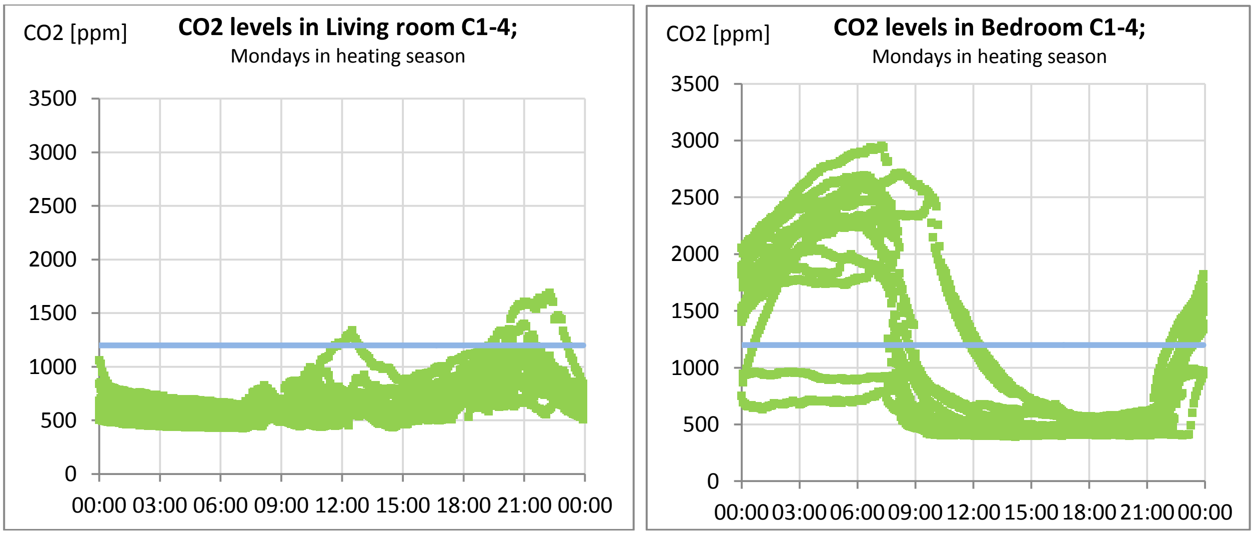


Figure 4.2.1.2 Illustrations of excess CO2 levels in the living room and bedroom of system C1.

System C.2c, Dwelling C2c-2 | Number of occupants: 3

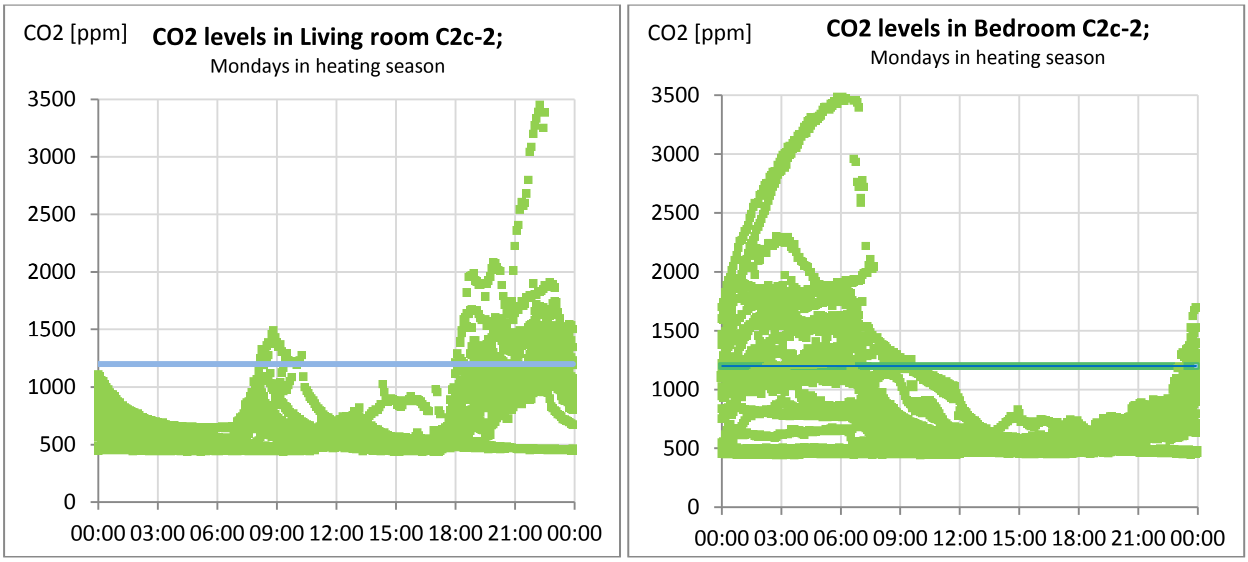


Figure 4.2.1.3 Illustrations of excess CO2 levels in the living room and bedroom of system C2.

Note:
In the intake interview, the occupant concerned indicated that both the ventilation grilles and the vent windows are permanently open in the bedrooms. In the living room, ventilation grilles are mostly closed, according to the occupant.

System C.4a, Dwelling C4a-3 | Number of occupants: 2

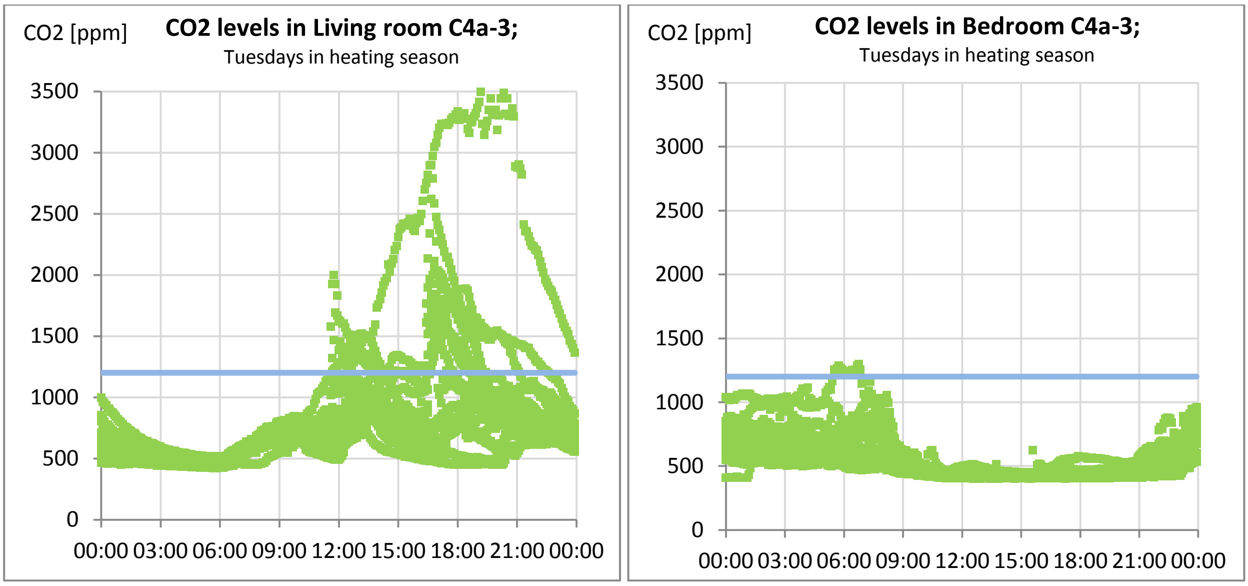


Figure 4.2.1.4 Illustrations of excess CO2 levels in the living room and bedroom of system C4a.

Note:
In the intake interview, the occupant concerned indicated that the ventilation grilles are permanently open in both the bedroom and the living room. The vent windows are opened for a couple of hours a day.

System C.4c, Dwelling C4c-4 | Number of occupants: 2

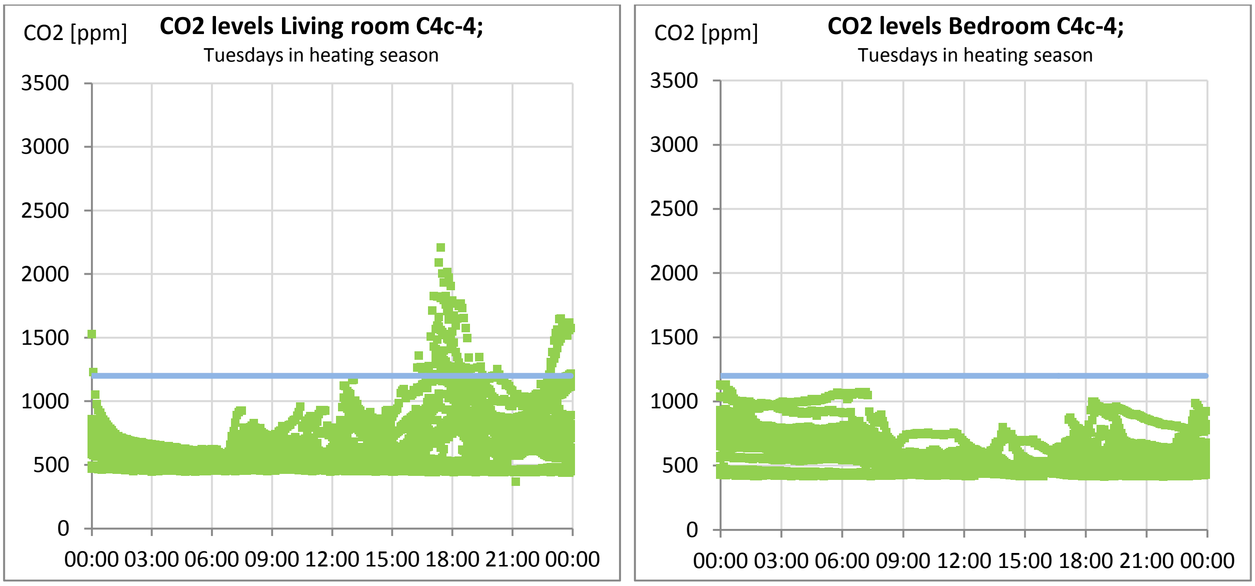


Figure 4.2.1.5 Illustrations of excess CO2 levels in the living room and bedroom of system C4c.

Note:
In the intake interview, the occupant concerned indicated that the ventilation grilles are permanently open in both the bedroom and the living room. The vent windows are opened in both rooms for a couple of hours a day on average.

System D.2, Dwelling D2-5 | Number of occupants: 5

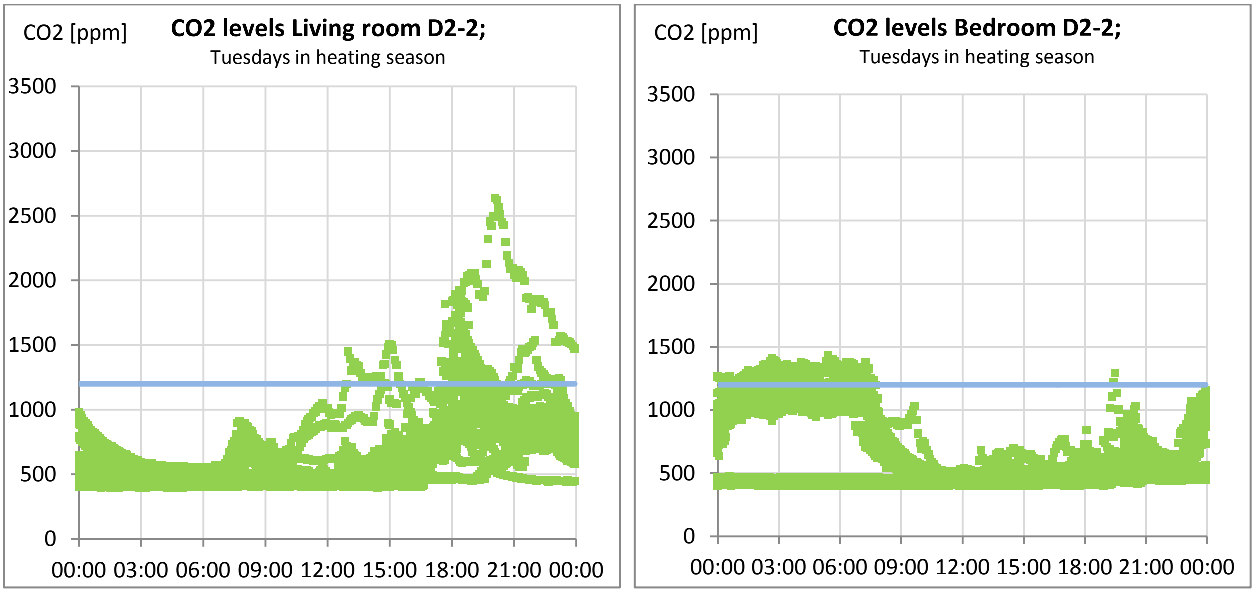


Figure 4.2.1.6 Illustrations of excess CO2 levels in the living room and bedroom of system D2.

System D.5a, Dwelling D5a-8 | Number of occupants: 3

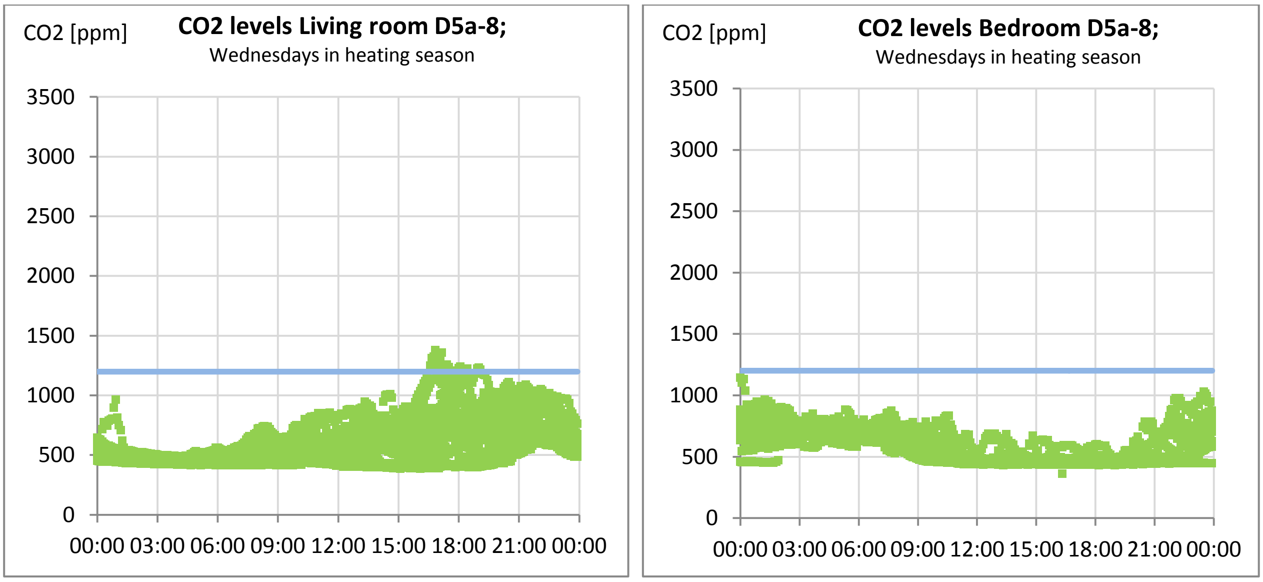


Figure 4.2.1.7 Illustrations of excess CO2 levels in the living room and bedroom of system D5a.

System D.5b, Dwelling D5b-2 | Number of occupants: 2

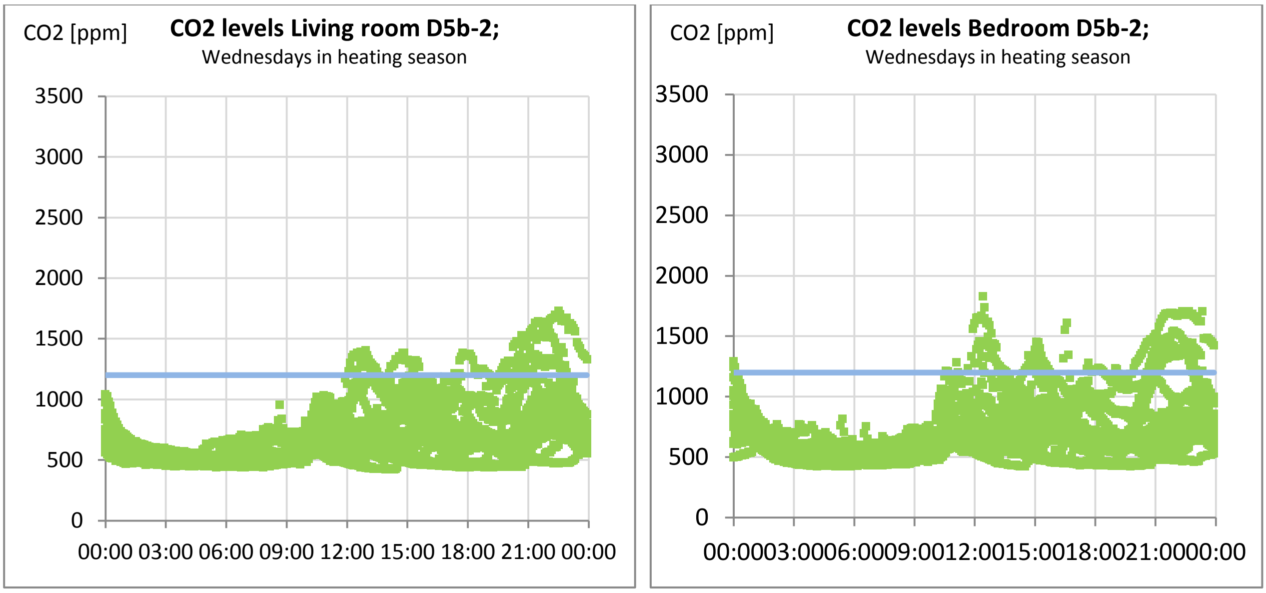


Figure 4.2.1.8 Illustrations of excess CO2 levels in the living room and bedroom of system D5b.

System D.x, Dwelling Dx-1 | Number of occupants: 2

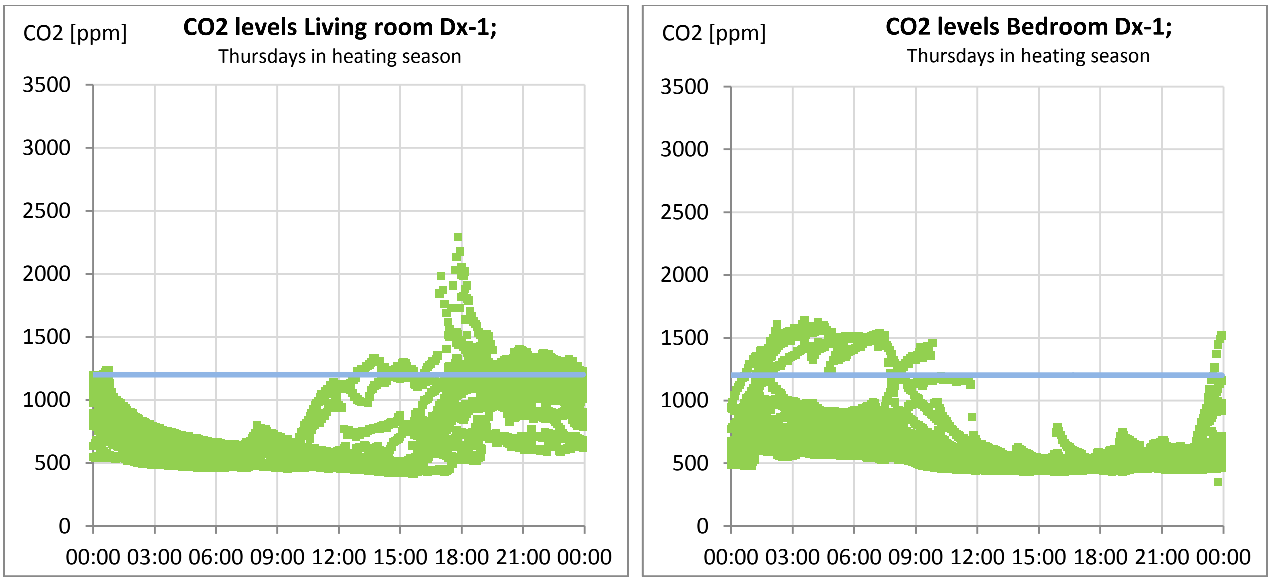


Figure 4.2.1.9 Illustrations of excess CO_2 levels in the living room and bedroom of system Dx.

System X1/C, Dwelling X1C-3 | Number of occupants: 2

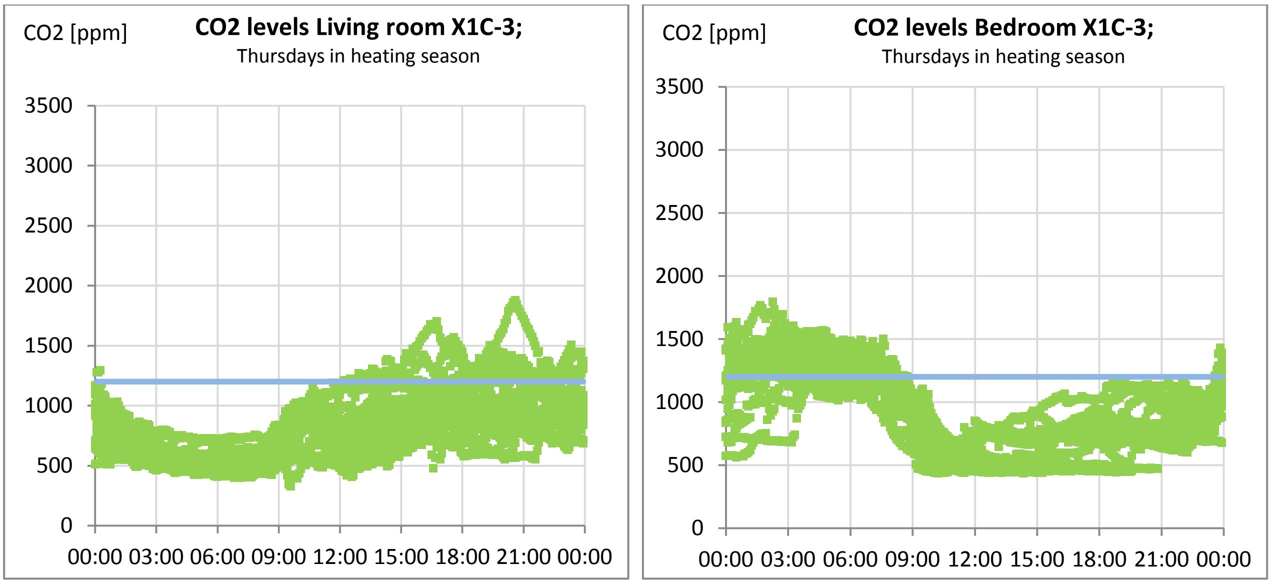


Figure 4.2.1.10 Illustrations of excess CO_2 levels in the living room and bedroom of system X1/C.

System X1/A, Dwelling X1A-3 | Number of occupants: 1

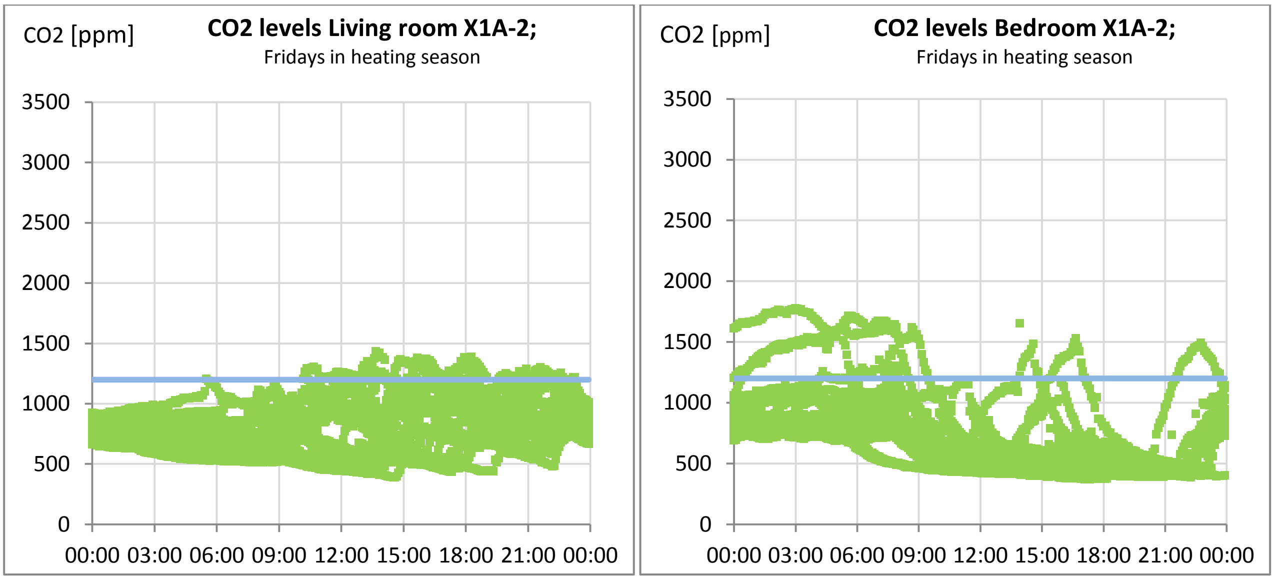


Figure 4.2.1.11 Illustrations of excess CO2 levels in the living room and bedroom of system X1/A.

Excess CO_2 levels in the habitable rooms are the result of the CO_2 load (in this case, the number of people present in the room) and the ventilation volumes realised in that room at that moment. After analysing how excess CO_2 levels develop in all rooms of the different homes and ventilation systems, the following picture is revealed.

If we assume that the CO_2 load over most of the heating season remains the same (excluding a few exceptions, e.g. when there are visitors) and also that actual ventilation volumes realised are more or less comparable, then the distribution of CO_2 concentrations should be limited. The graphs in this section show that this is not the case for a number of dwellings (dwellings with systems A, C1, C2c and C4a). The systems mentioned show a more than incidental distribution of CO_2 concentrations in living rooms and/or bedrooms. The related graphs rather illustrate a structural distribution of concentrations with multiple values that far exceed 1200 ppm, reaching as much as 3500 ppm CO_2. This implies that the ventilation volumes realised in the habitable rooms concerned must vary strongly.

The other dwellings with ventilation systems C4c, D2, D5a, D5b, Dx and partly also X1/C and X1/A show a much more moderate picture in terms of the distribution of CO_2 concentrations. This means that the ventilation volumes realised in the related habitable rooms are much more constant.

4.2.2

Total average CO2- excess doses per ventilation system

Per ventilation system, averages are determined of the parameters that typify CO2- excess doses over 1200 ppm. They include the following:

- Average duration of excess CO_2 levels in [hours/day]
- The average degree of excess CO_2 levels above 1200 ppm in [ppm]
- The average CO2- excess doses per day (duration x excess) in [ppmh/day]
- The average total CO2- excess doses per heating season in [kppmh/ht.ssn]

Because it is difficult to express the notion of CO2- excess doses in kppmh, the amount of time each person is exposed to CO_2 concentrations above 1200 ppm is also given and at which average values this limit is exceeded. Furthermore, an indication is given how long CO_2 concentrations are too high while occupants are at home. For this purpose it was assumed that the average occupant was at home for 63% of the day on average, about 15 hours a day. This figure is stated in the literature as the average presence fraction in your own home (see percentage in red in tables below).

Note 1.

The CO_2- excess doses calculated here and the excess dose per person are lower than the excess that actually occurred, as the calculation method used does not take account of the fact that multiple individuals may be exposed to CO_2- excess doses in a room (main bedroom). Dividing the total dose / heating season of exposure time by occupants to excess levels results as a rule in a value that is too low. Please take account of this when interpreting the results.

4.2.2.1 Ventilation system A

The average measured CO_2 -excess dose per person for system A amounts to 442 kppmh.

Per person, this dose lasts on average for 3.31 hours per day with an average concentration of (629 ppm above the upper limit) 1829 ppm CO_2. This means that on average ventilation is inadequate for about 22.1% of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM A		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	2.40	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Kitchen		2.00	669	1341	284
Bedroom 3		2.17	767	1665	353
Bedroom 2		3.12	854	2663	565
Bedroom 1		1.16	323	373	79
Living room		2.18	617	1346	285
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		9.76	689	6723	1425
Average per person		3.31	629	2084	**442**
Percentage of time at home		22.10%			

Table 4.2.2.1: Average CO2- excess doses System A

4.2.2.2 Ventilation system C.1

The average measured CO_2 -excess dose per person for system C.1 amounts to 349 kppmh.
Per person, this dose lasts on average for 3.51 hours per day with an average concentration of (468 ppm above the upper limit) 1668 ppm CO_2. On average ventilation is inadequate for about 23.43 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM C.1		**hours/day**	**av. value>1200**	**dose/day**	**dose/ht.season**
Av. no. occupants / dwelling	2.83	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Kitchen		1.97	353	694	147
Bedroom 3		1.97	1080	2124	450
Bedroom 2		3.26	427	1390	295
Bedroom 1		2.82	609	1716	364
Living room		1.93	383	738	157
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		10.95	512	5600	1187
Average per person		3.51	468	1644	**349**
Percentage of time at home		23.43%			

Table 4.2.2.2: Average CO_2 levels System C.1

4.2.2.3 Ventilation system C.2c

The average measured CO_2 -excess dose per person for system C.2c amounts to 244 kppmh.
Per person, this dose lasts on average for 3.41 hours per day with an average concentration of (337 ppm above the upper limit) 1537 ppm CO_2. On average ventilation is inadequate for about 22.74% of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM C.2c		**hours/day**	**av. value>1200**	**dose/day**	**dose/ht.season**
Av. no. occupants / dwelling	3.33	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Attic		3.55	186	660	140
Bedroom 3		4.10	470	1924	408
Bedroom 2		2.02	294	594	126
Bedroom 1		2.66	282	750	159
Open kitchen		2.46	317	780	165
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		12.42	344	4267	905
Average per person		3.41	337	1150	**244**
Percentage of time at home		22.74%			

Table 4.2.2.3: Average CO2- excess doses System C.2c

4.2.2.4 Ventilation system C.4a

The average measured CO_2 -excess dose per person for system C.4a amounts to 271 kppmh.
Per person, this dose lasts on average for 2.04 hours per day with an average concentration of (627 ppm above the upper limit) 1827 ppm CO_2. On average ventilation is inadequate for about 13.57 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM C.4a		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	2.75	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Kitchen		0.97	322	313	66
Bedroom 3		0.27	325	88	19
Bedroom 2		2.68	1043	2793	592
Bedroom 1		2.58	793	2043	433
Living room		1.19	298	356	75
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		7.62	731	5570	1181
Average per person		2.04	627	1277	**271**
Percentage of time at home		13.57%			

Table 4.2.2.4: *Average CO2- excess doses System C.4a*

4.2.2.5 Ventilation system C.4c

The average measured CO_2 -excess dose per person for system C.4c amounts to 72 kppmh.
Per person, this dose lasts on average for 1.4 hours per day with an average concentration of (243 ppm above the upper limit) 1443 ppm CO_2. On average ventilation is inadequate for about 9.31 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM C.4c		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	1.71	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Utility room					
Bedroom 3		0.07	222	15	3
Bedroom 2		1.08	238	258	55
Bedroom 1		0.95	200	190	40
Open kitchen		1.06	299	317	67
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		3.13	247	733	164
Average per person		1.40	243	340	**72**
Percentage of time at home		9.31%			

Table 4.2.2.5: *Average CO2- excess doses System C.4c*

4.2.2.6 Ventilation system D.2

The average measured CO_2 -excess dose per person for system D.2 amounts to 68 kppmh.
Per person, this dose lasts on average for 1.06 hours per day with an average concentration of (303 ppm above the upper limit) 1503 ppm CO_2. On average ventilation is inadequate for about 7.10 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM D.2		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	3.33	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Bedroom 3		0.82	274	224	47
Bedroom 2		0.73	220	161	34
Bedroom 1		1.12	263	294	62
Open kitchen		0.86	403	345	73
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		3.52	291	1024	217
Average per person		1.06	303	322	**68**
Percentage of time at home		7.10%			

Table 4.2.2.6: Average CO2- excess doses System D.2

Note: The average results in this group are not adjusted for the dwelling in which the supply fan is switched off by occupants.

4.2.2.7 Ventilation system D.5a

The average measured CO_2 -excess dose per person for system D.5a amounts to 105 kppmh.
Per person, this dose lasts on average for 1.04 hours with an average concentration of (479 ppm above the upper limit) 1679 ppm CO_2. On average ventilation is inadequate for about 6.92 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM D.5a		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	2.30	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Attic		0.38	334	125	27
Bedroom 3		1.46	658	958	203
Bedroom 2		0.71	294	209	44
Bedroom 1		0.09	182	17	4
Open kitchen		0.24	308	74	16
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling		2.65	494	1308	277
Average per person		1.04	479	497	**105**
Percentage of time at home		6.92%			

Table 4.2.2.7: Average CO2- excess doses System D.5a

Note: The average results in this group are not adjusted for the dwelling in which the supply valve is closed by occupants.

4.1.2.8 Ventilation system D.5b

The average measured CO_2 -excess dose per person for system D.5b amounts to 183 kppmh.
Per person, this dose lasts on average for 1.88 hours with an average concentration of (461 ppm above the upper limit) 1661 ppm CO_2. On average ventilation is inadequate for about 12.50 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM D.5b			hours/day	av. value>1200	dose/day	dose/ht.season
	Av. no. occupants / dwelling	2.00	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
	Kitchen		0.51	277	141	30
	Bedroom 2		1.80	778	1401	297
	Bedroom 1		0.70	383	268	57
	Living room		1.40	308	429	91
			Total time	av. value	Total dose/day	Total dose/ht.ssn
	Dwelling		4.40	509	2239	475
	Average per person		1.88	461	865	**183**
	Percentage of time at home		12.52%			

Table 4.2.2.8: *Average CO2- excess doses System D.5b*

Note: The average results in this group are not adjusted for a dwelling with a permanent CO2 load in a bedroom due to illness. The results are also not corrected for periods in which decentralised heat-recovery units are switched off by occupants.

4.2.2.9 Ventilation system D.x

The average measured CO_2 -excess dose per person for system D.x amounts to 76 kppmh.
Per person, this dose lasts on average for 1.82 hours with an average concentration of (198 ppm above the upper limit) 1398 ppm CO_2. On average ventilation is inadequate for about 12.11 % of the time when occupants are at home.

AVERAGE CO2- EXCESS DOSES SYSTEM D.x			hours/day	av. value>1200	dose/day	dose/ht.season
	Av. no. occupants / dwelling	2.00	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
	Bedroom 3		0.04	42	2	0
	Bedroom 2		0.12	89	11	2
	Bedroom 1		0.75	200	150	32
	Open kitchen		2.72	204	555	118
			Total time	av. value	Total dose/day	Total dose/ht.ssn
	Dwelling		3.63	198	718	152
	Average per person		1.82	198	359	**76**
	Percentage of time at home		12.11%			

Table 4.2.2.9: *Average CO2- excess doses System D.x*

4.2.2.10 Ventilation system X1/C

The CO_2 -excess dose per person measured for system X1/C as a whole amounts to 175 kppmh, the largest part of which is accounted for by the sleeping area which is fitted with ventilation system type C. Only a small part is accounted for by the living floor with decentralised heat recovery.
On average over the entire dwelling, the excess dose per person lasts on average for 2.93 hours with an average concentration of (283 ppm above the upper limit) 1483 ppm CO_2.
In the living room, the average time of exposure to excess doses is 0.66 hours per person with an average concentration of 1417 ppm CO_2. In the sleeping area, the average time of exposure to excess doses is 2.13 hours per person with an average concentration of 1551 ppm CO_2.

AVERAGE CO2- EXCESS DOSES SYSTEM X1/C		hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling	2.20	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Kitchen		0.71	321	228	48
Bedroom 3		0.24	114	27	6
Bedroom 2		2.21	230	508	108
Bedroom 1		2.24	496	1109	235
Living room		1.45	217	315	67
		Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling total		6.84	320	2186	463
Av. per person		2.93	283	827	**175**
Percentage of time at home		19.51%			
Sleeping area total		4.68	351	1644	349
Av. per person		2.13	351	747	158
Perc. time at home		14.18%			
Separate kitchen		0.71	321	228	48
Av. per person		0.32	321	103	22
Perc. time at home		2.15%			
Living area (excl. kitchen)		1.45	217	315	67
Av. per person		0.66	217	143	30
Perc. time at home		4.39%			

Table 4.2.2.10: Average CO2- excess doses System X1/C

Note:
The average results are not adjusted for the period in which decentralised heat-recovery units are switched off by occupants.

4.2.2.11 Ventilation system X1/A

The average CO_2 -excess dose per person for system X1/A as a whole amounts to 167 kkpmh. Per person, this dose lasts on average for 2.15 hours with an average concentration of (365 ppm above the upper limit) 1565 ppm CO_2.

In the living room, the average time of exposure to excess doses is 1.27 hours per person with an average concentration of 1502 ppm CO_2. In the sleeping area, the average time of exposure to excess doses is 0.67 hours per person with an average concentration of 1440 ppm CO_2.

AVERAGE CO2- EXCESS DOSES SYSTEM X1/A	hours/day	av. value>1200	dose/day	dose/ht.season
Av. no. occupants / dwelling 1.33	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]
Kitchen	0.66	574	379	80
Bedroom 2	0.28	236	67	14
Bedroom 1	0.60	242	146	31
Living room	1.27	302	384	81
	Total time	av. value	Total dose/day	Total dose/ht.ssn
Dwelling total	2.82	346	976	207
Av. per person	2.15	365	787	**167**
Perc. of time at home	14.36%			
Sleeping area total	0.89	240	213	45
Av. per person	0.67	240	160	34
Perc. time at home	4.43%			
Separate kitchen	0.66	574	379	80
Av. per person	0.50	574	284	60
Perc. time at home	3.30%			
Living area (excl. kitchen)	1.27	302	384	81
Av. per person	0.96	302	288	61
Perc. time at home	6.37%			

Table 4.2.2.11: Average CO2- excess doses System X1/A

Note:
The average results are not adjusted for the period in which decentralised heat-recovery units are switched off by occupants.

4.2.3
Comparison CO2- excess doses ventilation systems

4.2.3.1
Duration of excess CO_2 levels in hours per day

Table 4.2.3.1 below illustrates the duration of the average excess CO_2 levels in hours per day for the entire dwelling for all ventilation systems studied. It is also indicated per system which part of these excess hours is accounted for by living room / kitchen, and which part is due to bedrooms. The following issues are notable:

1.
The number of hours with excess CO_2 levels is greater for systems A, C1, C2c, C4a and X1/C than for the other systems. These five systems all involve habitable rooms that only use natural supply and extract facilities (ventilation grilles and overflow facilities).

2.
The largest number of hours of excess CO_2 levels is accounted for by bedrooms (with the exception of systems Dx and X1/A)

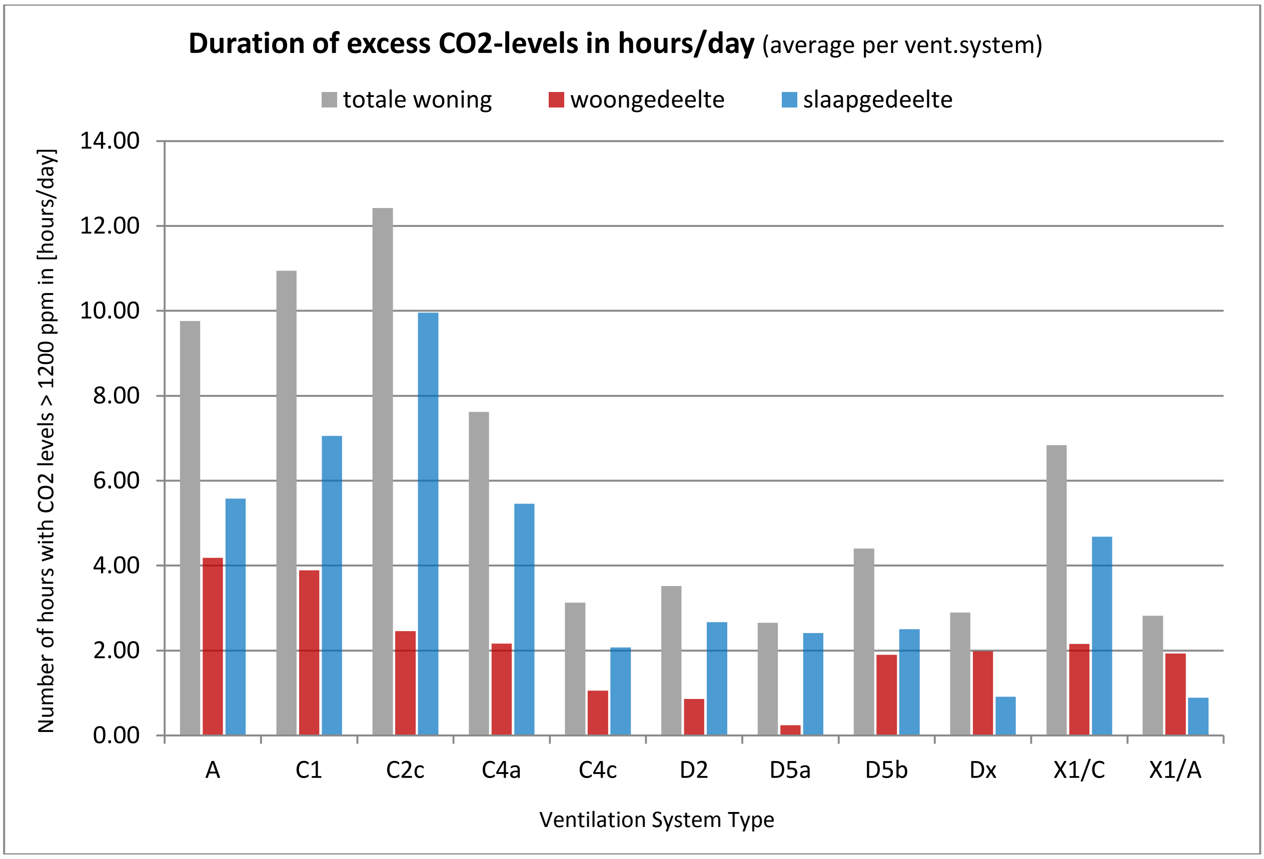


Figure 4.2.3.1: Average number of hours with excess CO2 levels per ventilation system

The average number of hours of excess CO_2 levels for habitable rooms with only *natural* supply and extraction facilities amounts to 4.63 hours/day. For habitable rooms with *mechanical* supply and/or extraction components, the average number of hours of excess levels is 1.71 hours/day.

4.2.3.2
Degree of excess CO_2 levels > 1200 ppm

Figure 4.2.3.2 shows the average degree of excess per system above the upper limit of 1200 ppm CO_2. These averages are initially calculated per individual dwelling, and then the average is determined for all dwellings with the same ventilation system.
The graph shows that values for systems with only natural supply and extraction facilities in the habitable rooms are also slightly higher on average than for the other systems, although the differences here are less pronounced.

When excess doses are averaged across the individual habitable rooms, then the average for habitable rooms with only natural supply and extraction components (ventilation grilles and overflow facilities) is 469 ppm. For habitable rooms with a mechanical component in the supply and/or extraction facilities, the average is 303 ppm.

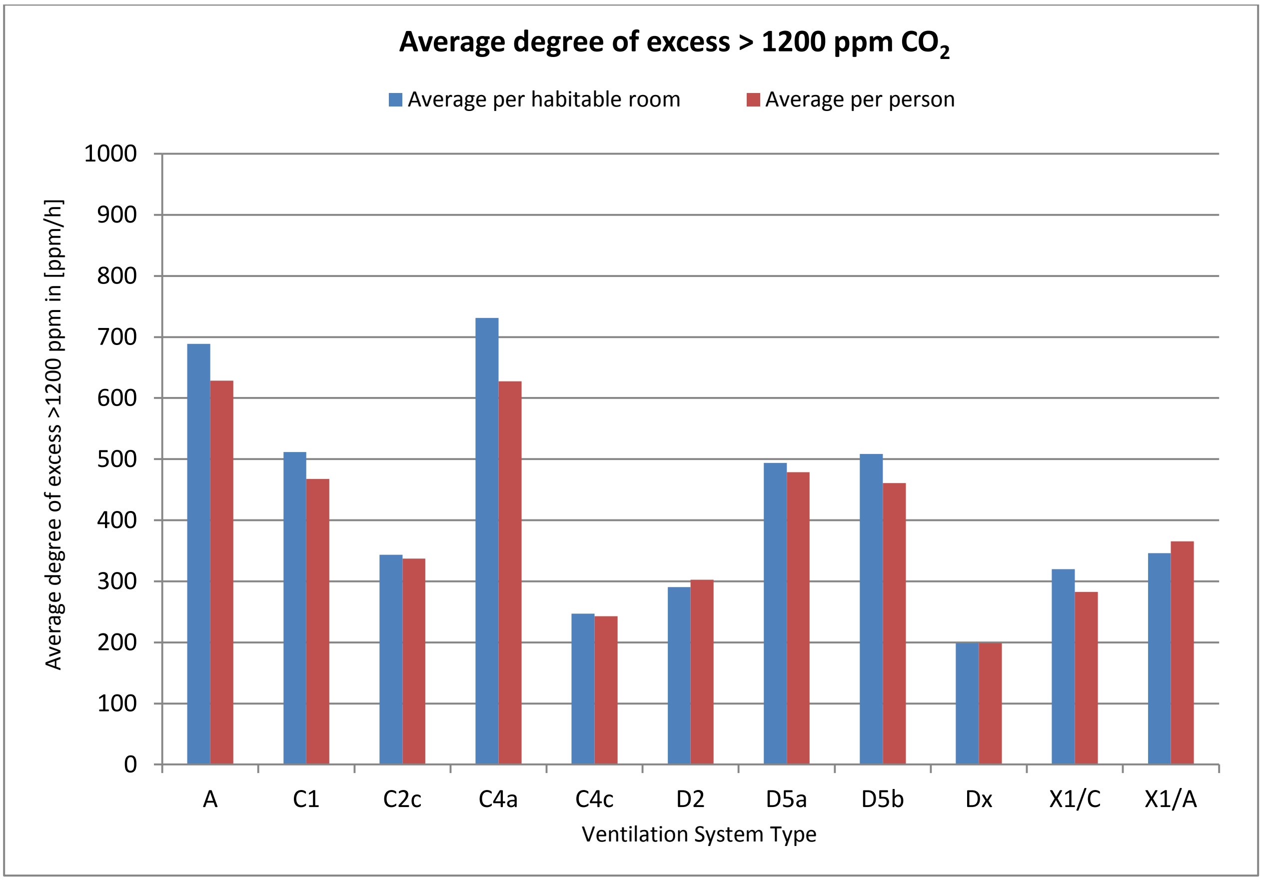


Figure 4.2.3.2: The average degree of excess CO2 levels >1200 ppm per ventilation system

Note 1: The higher values of systems D5a and D5b are to a large degree the result of undesired intervention by occupants of a few dwellings: for one D5a system the supply component in a bedroom is (partially) closed and for one D5b system several decentralised heat-recovery units were switched off temporarily. The results are not adjusted for this undesired behaviour.

Note 2: The CO_2-excess dose calculated here per person is lower than the excess that actually occurred, as the calculation method used does not take account of the fact that multiple individuals may be exposed to excess CO2 levels in a room (main bedroom). Dividing the total dose / heating season of exposure time by occupants to excess levels results as a rule in a value that is too low. Please take account of this when interpreting the results.

4.2.3.3

CO2- excess doses per heating season in kppmh

Figure 4.2.3.3 gives the total CO2- excess doses per ventilation system in kppmh (= product of hours of excess and the level of the excess) per heating season, for both the dwelling as a whole and per person. The graph shows that the average highest CO_2 load is measured in dwellings with ventilation system A, followed by dwellings that use ventilation system C, with only natural supply and extraction facilities in the habitable rooms (C1, C2c and C4a). Dwellings with ventilation systems that use a mechanical component in the supply and/or extraction facilities of the habitable rooms (systems C4c, D2, D5a, D5b, Dx, X1/C and X1/A) show a lower CO_2 load. The relatively poorer scores in this last group of dwellings (systems D5a, D5b and X1/C) are caused by undesired use of the ventilation facilities concerned (occupants that switch off fans and/or decentralised heat-recovery units and/or who (partially) close air supply valves (systems D5a, D5b) or due to the fact that half the dwelling is ventilated by systems with natural supply and extraction facilities in the habitable rooms (systems X1/C).

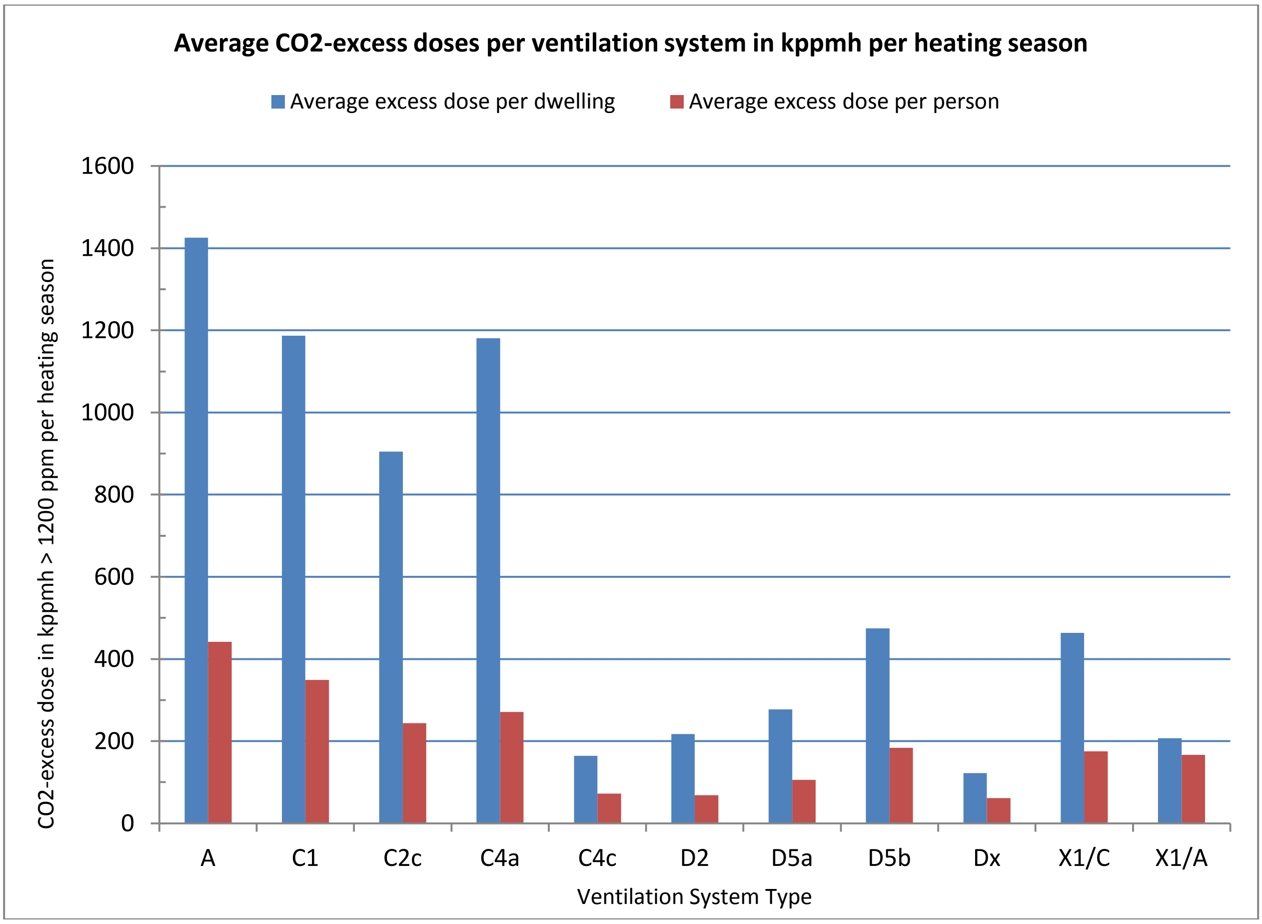


Figure 4.2.3.3: Average CO2- excess doses per ventilation system in kppmh per heating season

Note: The CO2- excess doses calculated here in kppmh per heating season per person are lower than the excess that actually occurred, as the calculation method used does not take account of the fact that multiple individuals may be exposed to CO_2-excess doses in a room (main bedroom). Dividing the total dose / heating season of exposure time by occupants to excess levels results as a rule in a value that is too low. Please take account of this when interpreting the results.

Figure 4.2.3.4 shows the distribution of the average CO_2-excess doses in kppmh per person per part of dwelling. Bedrooms are the habitable rooms in which the largest CO_2 –excess doses occur, followed by living rooms (plus open kitchen) and separate kitchens.

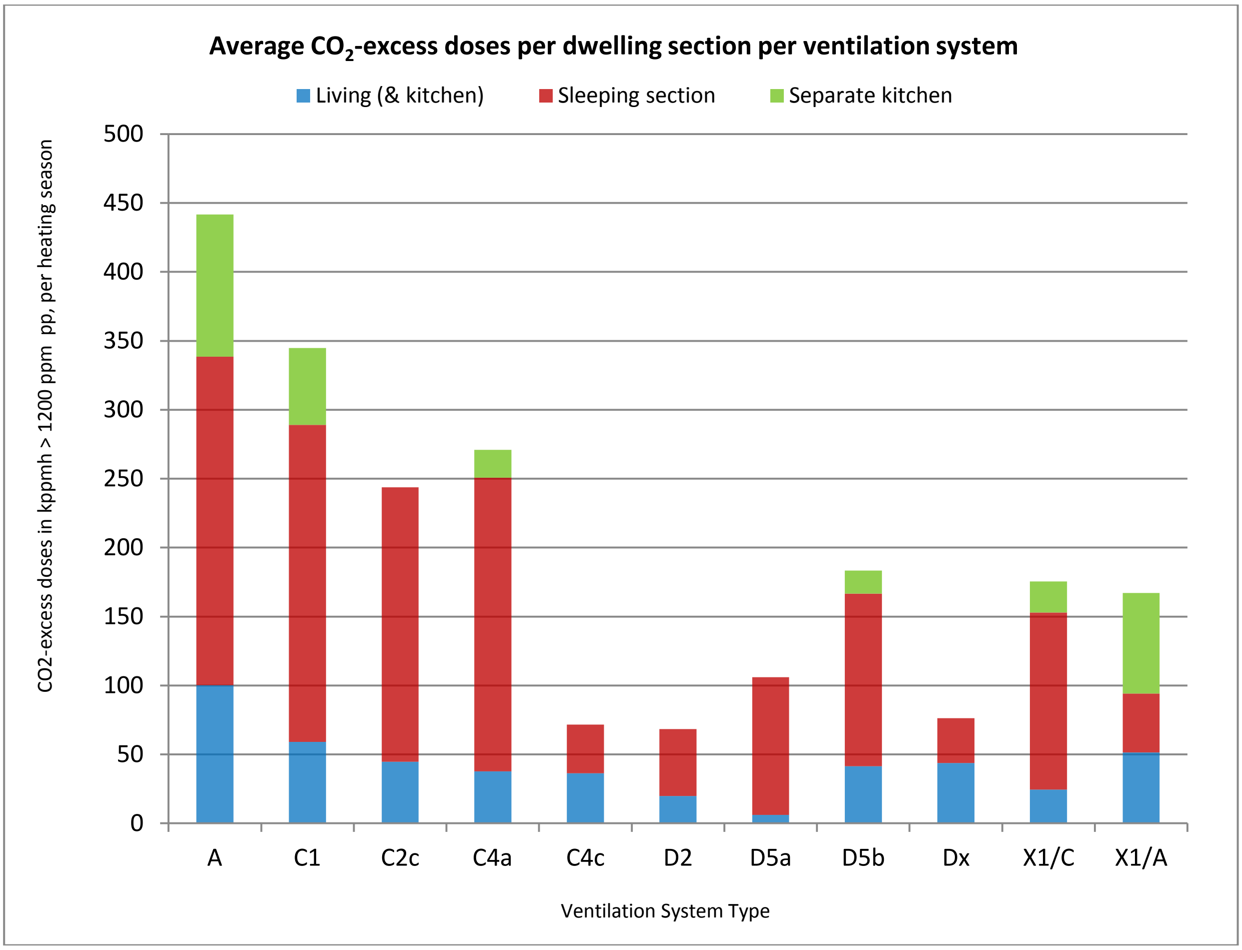


Figure 4.2.3.4 Average CO2- excess doses in kppmh per part of dwelling

4.2.3.4

Distribution of CO_2 -excess doses [in kppmh/pp] per group of dwellings with the same ventilation system

Figure 4.2.3.5 gives an overview of average CO_2-excess doses per person per individual dwelling in a group of dwellings with the same ventilation system.

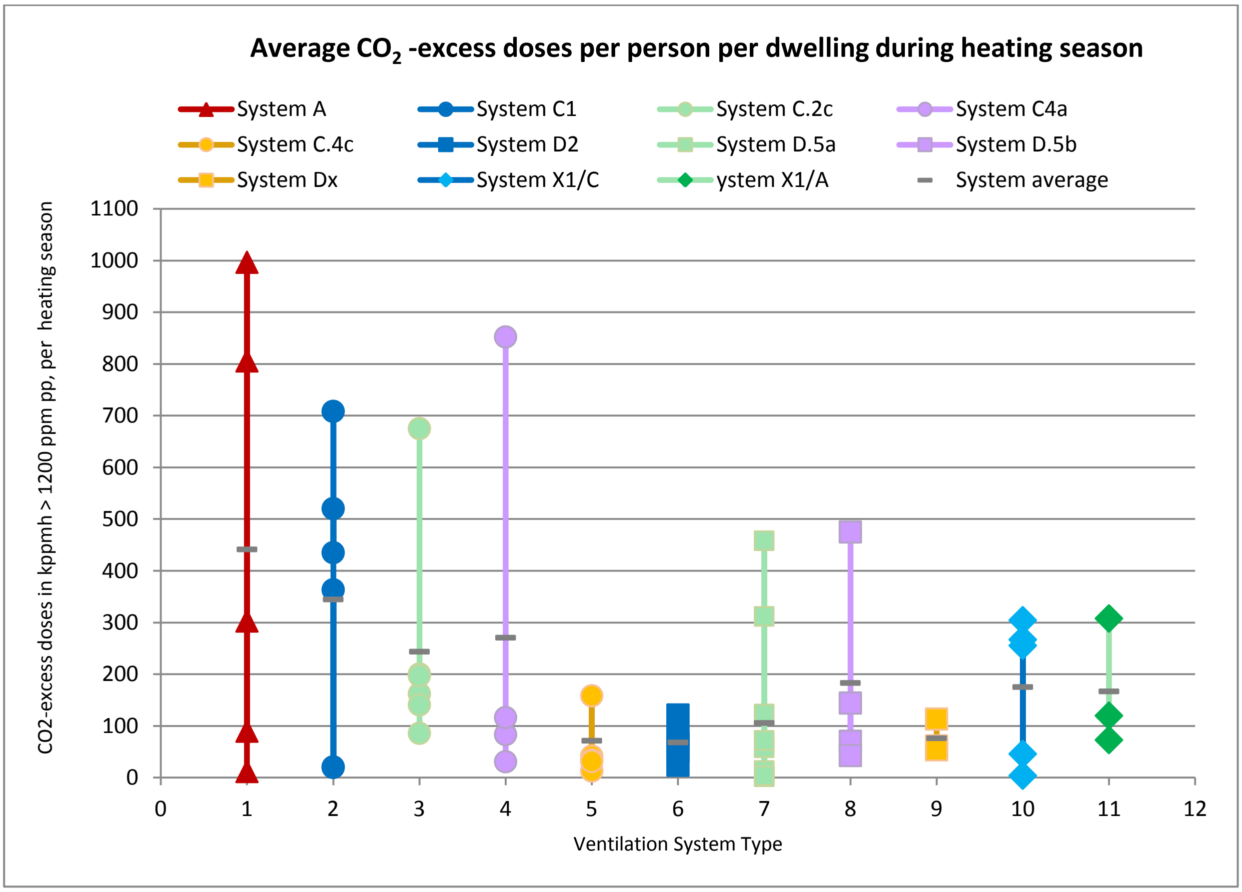


Figure 4.2.3.5: Average CO_2- excess doses in kppmh per person per dwelling per heating season

The figure shows that systems A, C1, C2c, and C4a have a wider distribution in average CO_2 excess doses (kppmh) per person than the other systems. This implies that the ventilation volumes realised in the habitable rooms of dwellings with these systems vary strongly. The figure also shows that these systems have a higher average CO_2 excess dose (kppmh) per person, and that they consequently achieve lower ventilation flow rates in the habitable rooms of these dwellings.

Figure 4.2.3.6 shows the standard deviation on the average CO_2 -excess doses (in kppmh per person per heating season). The greatest distribution occurs in bedrooms with only natural supply and extraction facilities. Assuming that the number of people in these bedrooms does not vary too much, this means that the ventilation volumes there vary more strongly.

Also a number of dwellings with mechanical components in the supply and/or extraction provisions in the bedrooms (systems D5a and D5b) show a slightly greater distribution. Detailed analyses of these dwellings suggest that occupants have intervened in the mechanical system (partially) closing supply valves or switching off local heat-recovery units). The reason for this is how people experience draughts and/or noise.

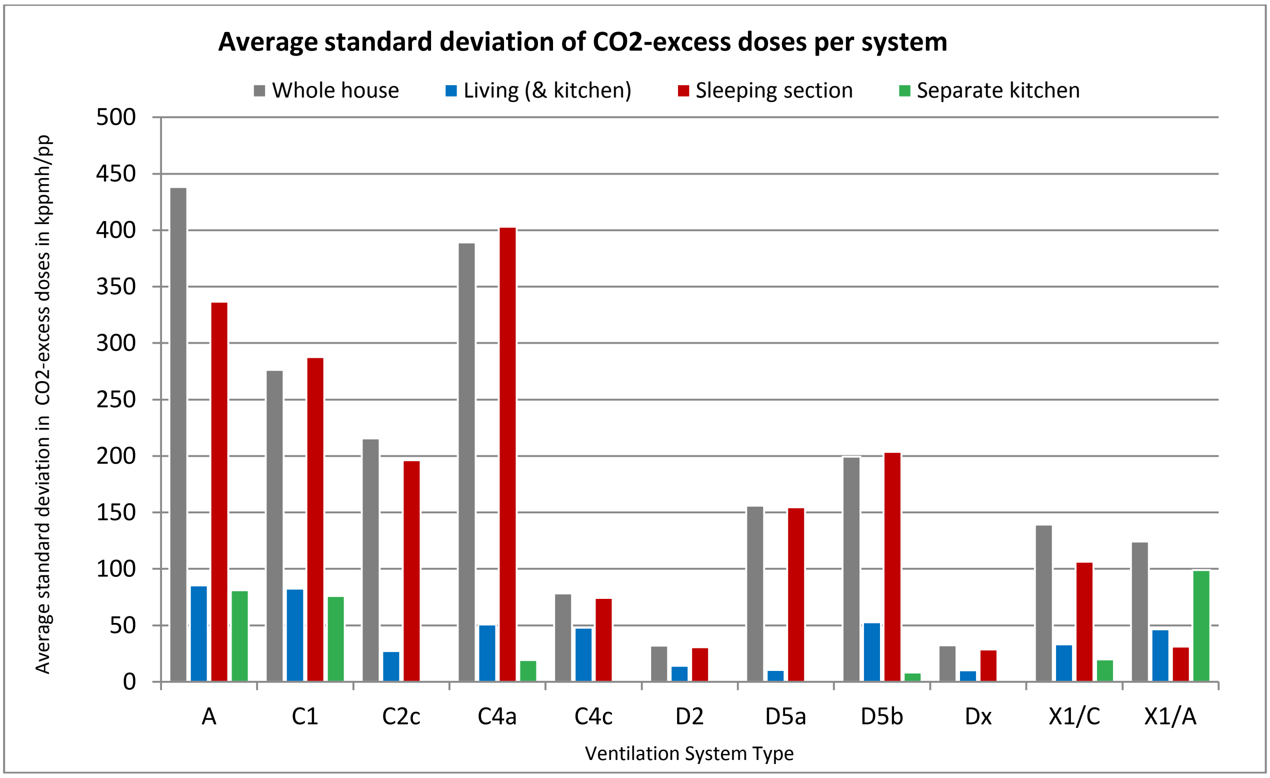


Figure 4.2.3.6: Average standard deviation of the CO_2-excess doses in kppmh per person per heating season

The table below shows, for each group of ventilation systems, the average value of the measured CO_2 -excess doses >1200 ppm in kppmh per person per heating season

System group	Av. CO2- excess doses s in kppmh/pp				
	total dwelling	standard deviation	*living section*	*kitchen*	*sleeping section*
System A (LA with natural supply and extraction)	**442**	438	*100*	*103*	*239*
Systems C1, C2c and C4a (LAs with natural supply and extraction)	**290**	271	*48*	*26*	*214*
System C4c (VGs with natural supply and mechanical extraction)	**72**	78	*36*	*-*	*35*
Systems D2, D5a, D5b, Dx (VGs with mechanical supply and/or extraction)	**106**	132	*21*	*3*	*82*
Systems X1/C and X1/A Living room (mech. supply and extraction); Bedroom (nat. sup. and ext.)	**172**	125	*35*	*41*	*96*

Table 4.1.3.7: Average CO2- excess doses >1200 ppm in kppmh per person per heating season for the different groups of ventilation system.

4.2.4

Correlation of CO2- excess doses and number of occupants

Figures 4.2.4.1 to 4.2.4.5 show the correlation between the number of occupants and the average CO2-excess doses in kppmh per person per dwelling for the different system groups:

- System A
- Systems C1, C2c, C4a
- System C4c
- Systems D2, D5a, D5b, Dx
- Systems X1/C and X1/A

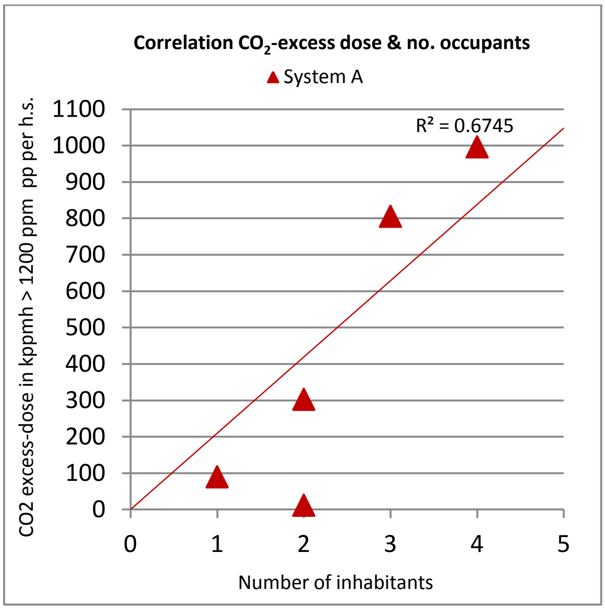


Figure 4.2.4.1
Correlation CO2- excess doses & number of occupants system A

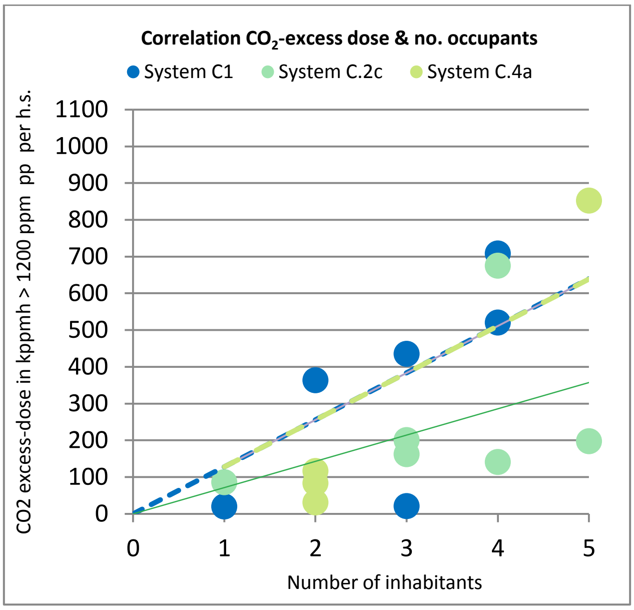


Figure 4.2.4.2
Correlation CO2- excess doses & number of occupants system C1,2c,C4a

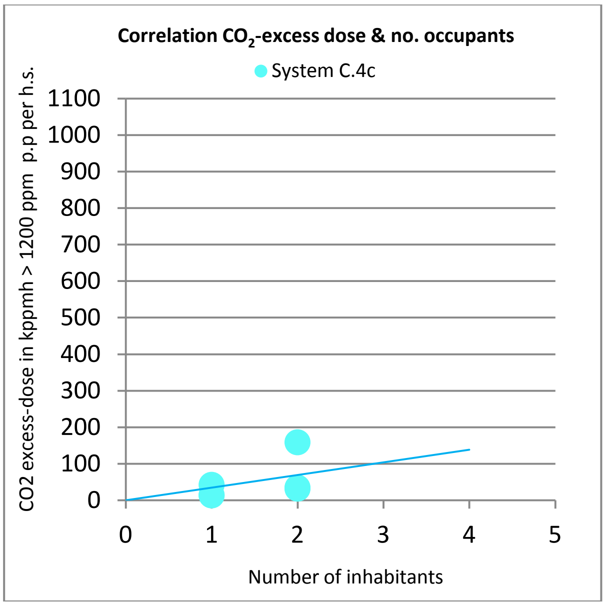


Figure 4.2.4.3
Correlation CO2- excess doses & number of occupants system C4c

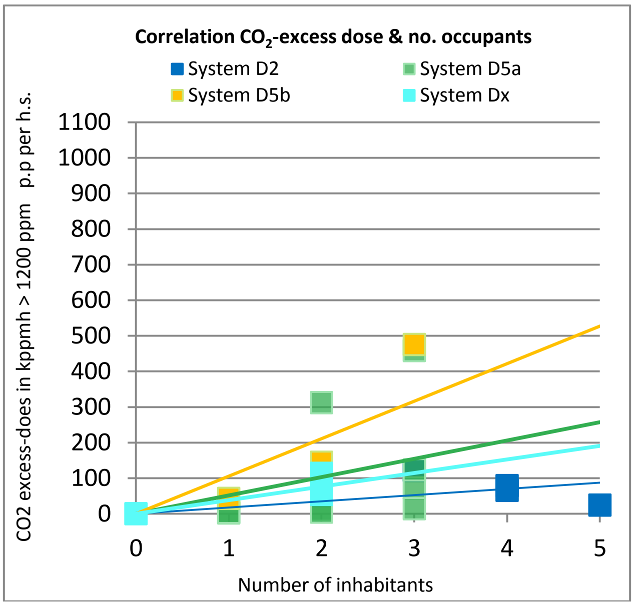


Figure 4.2.4.4
Correlation CO2- excess doses &number of occupants syst. D2, D5a, D5b, Dx

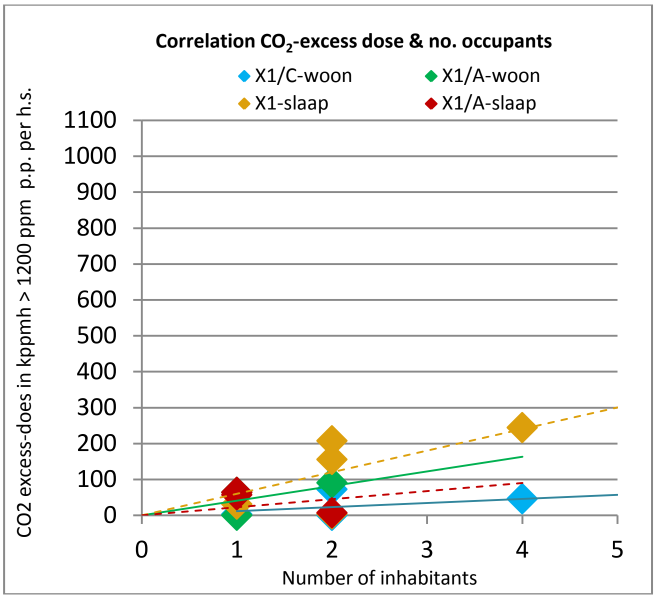


Figure 4.2.4.5
Correlation CO2- excess doses & number of occupants system X1/C and X1/A

Although the random sample is on the small side to draw any solid conclusions, the following picture is revealed:

1.

If the dwelling only has one occupant, then all ventilation systems realise an CO2- excess doses of comfortably below 100 kppmh per person.

2.

In terms of their performance on indoor air quality, all ventilation systems show a certain correlation with the size of the family. The higher the number of occupants, the higher the CO2- excess doses s.

3.

Systems with only natural supply and extraction facilities in habitable rooms (systems A, C1, C2c and C4a) show a stronger correlation between the number of occupants and CO2- excess doses than systems with a mechanical component in the habitable rooms. For systems with mechanical extraction in the wet rooms, and natural supply and extraction facilities in the habitable rooms (systems C1, C2c, C4a), this correlation too is slightly less pronounced than for system A. Strangely enough, system C4a (with a CO_2 sensor in the living room) does not perform better than the systems without a CO_2 sensor (C1 and C2c).

4.

Systems with a mechanical component in the habitable rooms show the lowest correlation between CO2- excess doses and the number of occupants, and therefore appear to be more capable of keeping CO_2 concentrations in habitable rooms at more acceptable levels.

4.2.5
Correlation CO2- excess doses and air-tightness of the dwelling

Figure 4.2.5.1 illustrates the relationship between the qv10 value (= air tightness) of the dwellings and the average CO2- excess doses realised per person for that dwelling. The generally accepted idea that leaky homes (dwellings with a high qv10 value) provide better air quality is not borne out by the Monicair data. On the contrary, the opposite actually appears to be the case. Further detailed analysis shows that air-tight dwellings ($qv_{;10;char} < 1.0$ l/s/m^2) more often have a ventilation system with a mechanical component fitted in the habitable rooms and for that reason have lower CO2- excess doses . This explains the fact that in the Monicair random sample air-tight dwellings on average indicate better air quality.
But the air-tightness tests carried out for the Monicair study suggest that given the location of these leaks they have little or no impact on indoor air quality in habitable rooms. After all, this relates in many cases to locations not found in habitable rooms, such as roof ducting for CH boilers and ventilation systems, cellar windows, toilet windows, the seals between attic floor and roof, meter cupboards, crawl-space hatch, etc.

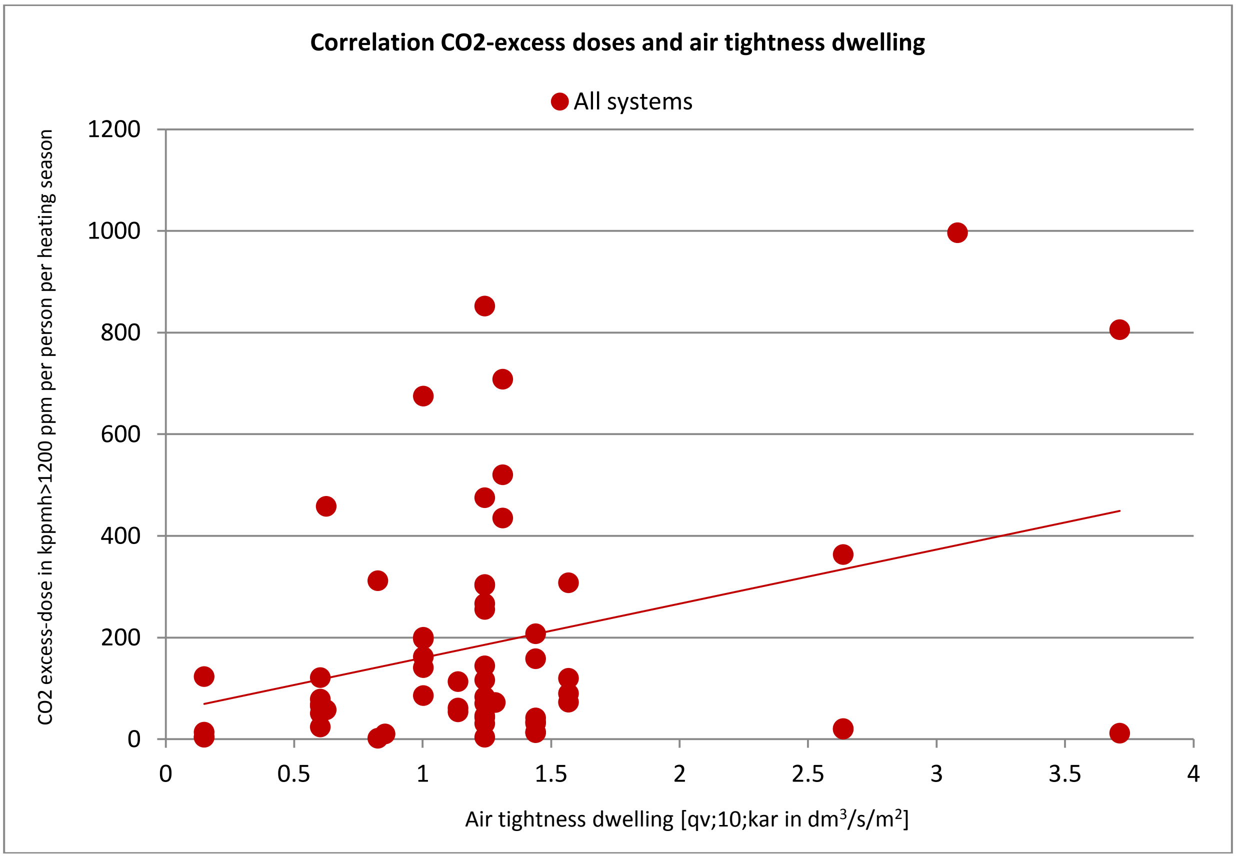


Figure 4.2.5.1: Correlation between average excess CO2 level per person per dwelling and the related air-tightness of the dwelling.

4.2.6
Correlation of CO2- excess doses and mechanical ventilation rates

The average mechanical ventilation flow rates for the entire dwelling show little or no effect on CO2-excess doses in the different habitable rooms. Figure 4.1.6.1 shows that the correlation between the average ventilation flow rates in the dwelling and the average CO2- excess doses per person is extremely weak (in figure 4.1.6.2 this correlation is even completely absent).

Figure 4.1.6.1 covers dwellings with ventilation systems that mechanically extract air from the wet rooms and naturally supply and extract air to/from the habitable rooms (systems C1, C2c and C4a). Only the dwellings for which the mechanical extraction flow rates could be tested (11 of the 16 dwellings) are included in this graph. Only three of these 11 homes have a CO_2 percentage of below 100 kppmh / per person. Further, of these 3, there are 2 with just a single occupant and therefore a minimal CO_2 load.

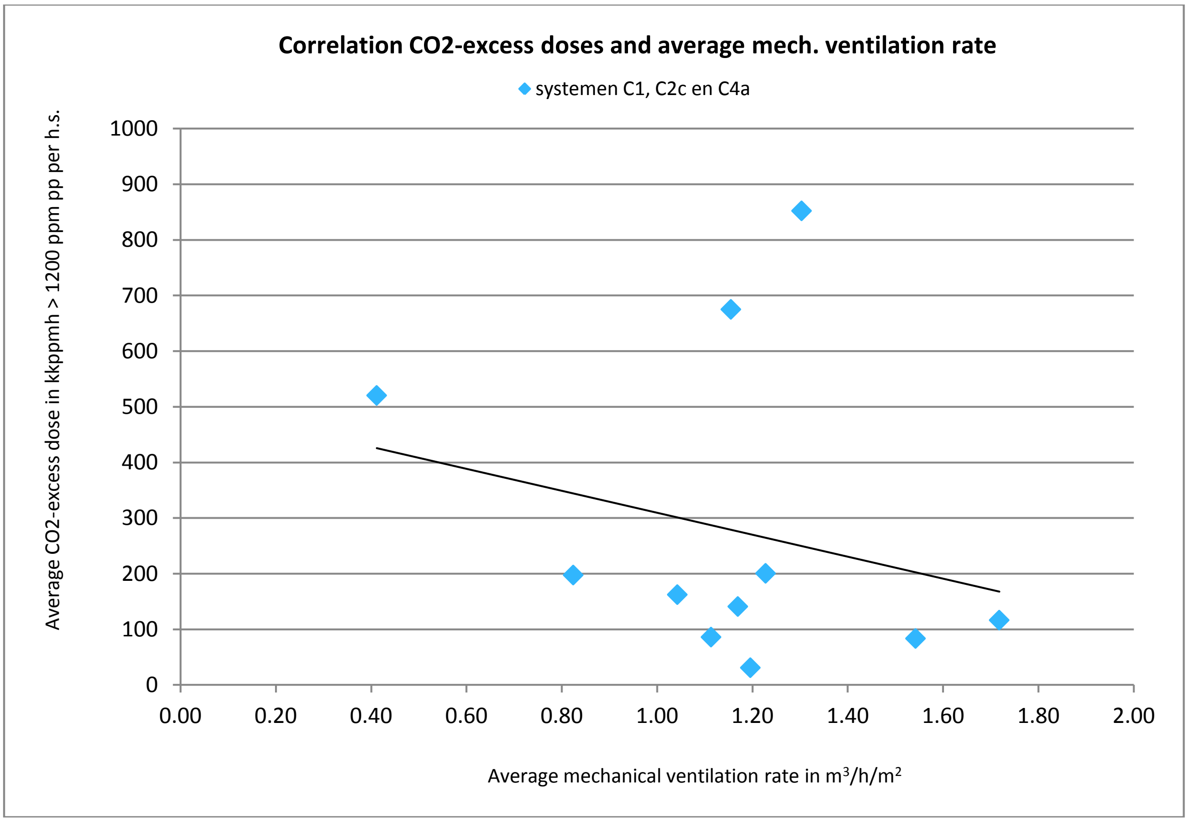


Figure 4.2.6.1: Correlation between average CO2- excess doses per person per dwelling and realised average mechanical ventilation flow in m3/h/m2

If the average is calculated for all dwellings with systems C1, C2c and C4a, then average CO2- excess dose is **288 kppmh/pp** at an average ventilation flow rate of **1.15 m3/h/m2**

Figure 4.2.6.2 covers dwellings with ventilation systems that, in addition to mechanical extraction from the wet rooms, also have a mechanical component in the habitable rooms.
A majority of these homes have CO2- excess doses lower than 100 kppmh/pp. The three dwellings with CO2- excess doses above 300 kppmh/pp are the homes in which the occupant has incorrectly intervened in the ventilation system due to draughts and/or noise problems. Incorrect actions are understood to include 'closing supply valves', 'temporarily switching off a (decentralised) heat-recovery unit, or turning off the central supply fan.

If the average is calculated for all dwellings with systems C4c, D2, D5a, D5b and Dx, then average CO2-excess dose is **98 kppmh/pp** at an average ventilation flow rate of **0.95 m3/h/m2**

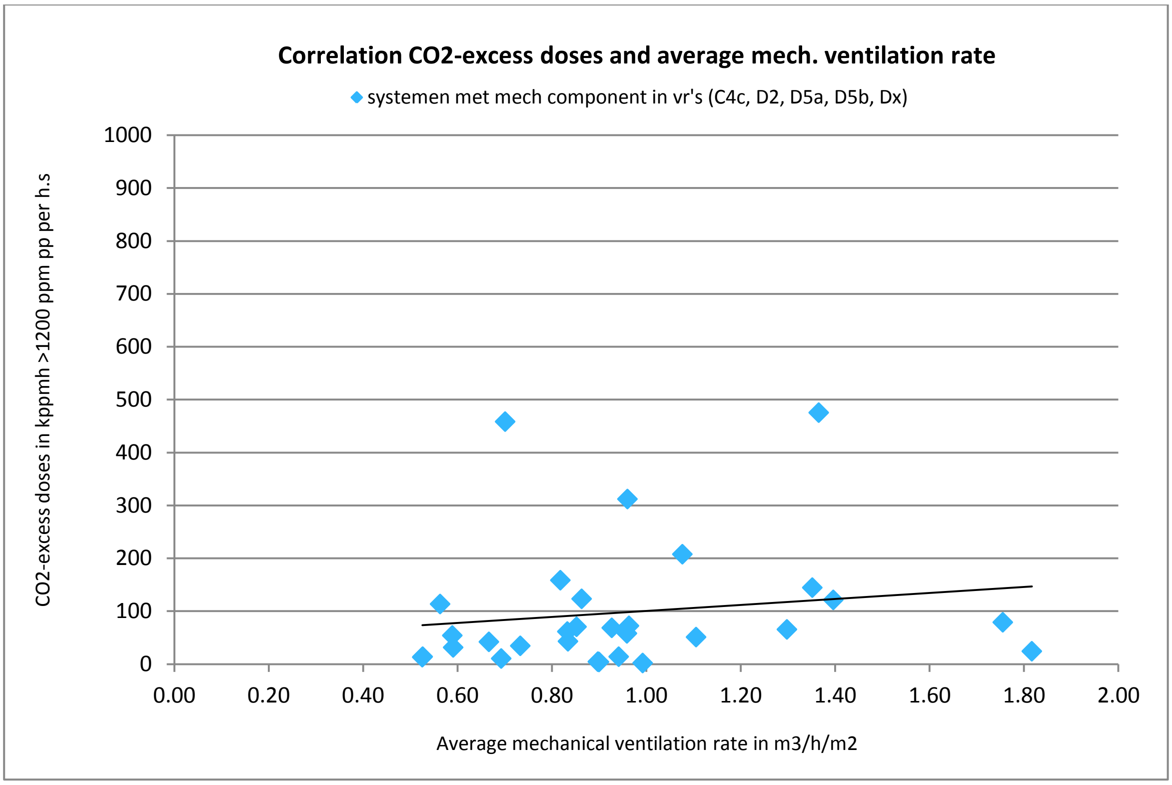


Figure 4.2.6.2: Correlation between average CO2- excess doses per person per dwelling and realised average mechanical ventilation flow rate in m3/h/m2

These considerations lead to the conclusion that raising total average ventilation flow rates from, for instance, 1.0 to 1.5 $m^3/h/m^2$ (e.g. by turning up the 3-position switch of the central ventilation unit) would have little or no impact on CO_2- excess doses in habitable rooms.

This conclusion seems at first to be contradictory. There must of course be a correlation between the CO_2 source (number of occupants) in a habitable room and the ventilation flow rates realised there. That this correlation is not detected at the level of the analysis carried out means that:

1. Raising mechanical ventilation levels throughout the dwelling (via turning up the central ventilation unit) will have little or no effect on ventilation flow rates in the habitable rooms. This applies mainly to systems with natural supply and extraction components in the habitable rooms (systems A, C1, C2c and C4a)
2. The increase in central mechanical ventilation flow rate is too small related to the CO_2 increase in a specific room. When the CO2-emission is increased (three or four people instead of one person), the ventilation flow rates in the room concerned should in theory also be increased by a factor of 3 or 4 (e.g. from 25 m3/h to ca. 100 m3/h). An increase in central mechanical flows by 50% will only have a limited effect if the CO_2-emission increases by a factor of three or four. This applies to all ventilation systems.

Figure 4.2.6.2 (see previous page) relates to systems with a mechanical component in the habitable rooms and should therefore at least show a certain degree of correlation. However, this graph shows ventilation flow rates in m3/h/m2. This says nothing about the CO_2 source (number of people) – in other words higher flow rates per m2 do not yet mean higher ventilation in relation to the CO_2 source. The graph below (Figure 4.2.6.3) therefore shows the CO2- excess doses of these systems in relation to mechanical ventilation flow rates expressed in m3/h per person.

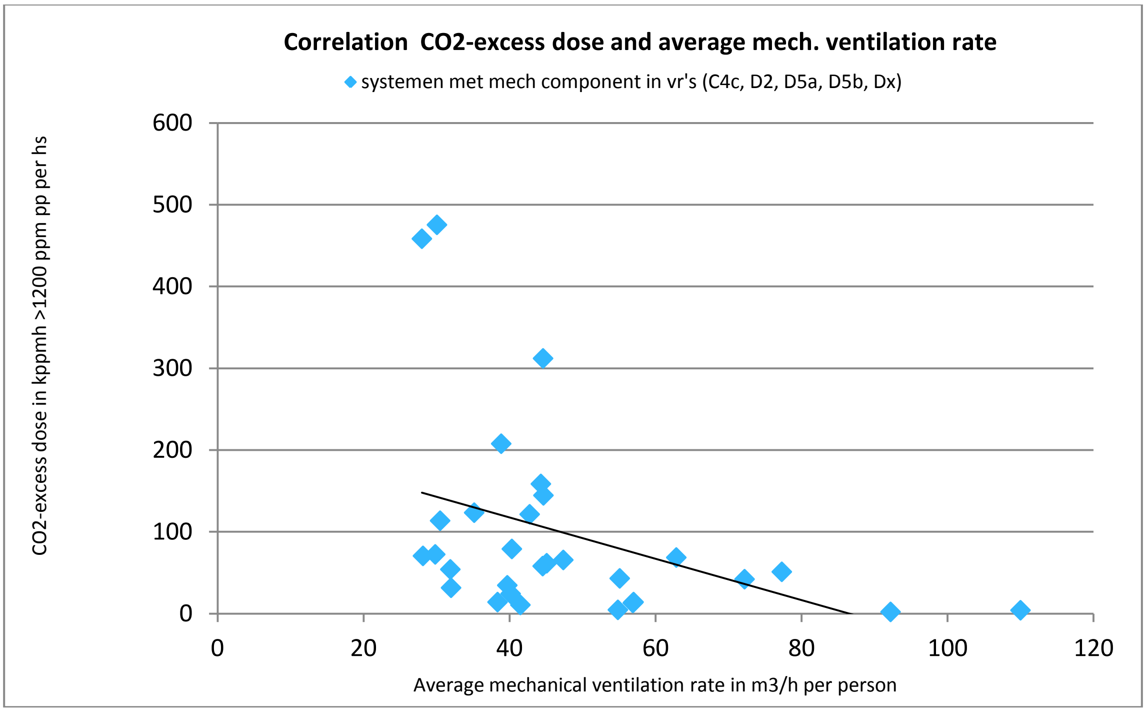


Figure 4.2.6.3: Correlation between average CO2- excess doses per person per dwelling and the realised average mechanical ventilation flow rates in m3/h per person

Figure 4.2.6.3 suggests that raising average mechanical ventilation flow rates per person has an impact – albeit a limited one – on CO2- excess doses . This figure implies not only that the variations in the CO_2 source per habitable room are clearly greater and more dominant than the related variation in ventilation volumes. Figure 4.1.6.3 also illustrates that increasing total ventilation flow rates across the dwelling would only have a limited impact on ventilation flow rates per person in a specific habitable room. For flow rates of more than 30 m3/h per person, CO2- excess doses should after all be minimal. That the CO2- excess doses in figure 4.1.6.3 are still significant means that the *average* flow rates per person calculated for the entire dwelling do not correspond with the average flow rates actually realised per person in a specific habitable room.

Sample calculation for system with mechanical component in habitable rooms:
For example, a living room of 30 m2 is ventilated (with the 3-position switch in setting 1) at 0.3 l/s per m2 (see also § 4.1.1), or 32 m3/h for the entire living room. With one person present, this is more than enough. However, with three or four people present in the living room, ventilation volumes are inadequate and CO2- excess doses accumulate. When the 3-position switch is switched to setting 2, and ventilation flow rates increase to, for instance, 0.6 l/s per m2 of habitable room, or 64 m3/h for the entire living room, CO_2 levels may well be reduced yet are still excessive. This is despite total ventilation volumes for the entire dwelling (at ca. 130 m3/h) being comfortably sufficient to prevent CO2- excess doses in the living room. The same story applies to a main bedroom of say 14 m2. In setting 1 of the 3-position switch, this room is ventilated at 15 m3/h. Even for one person at rest, this is on the low side, but with two people present, CO2- excess doses will arise here too. And this remains the case even when flow rates are increased by 50% and total flow rates across the entire dwelling are sufficient to present CO2- excess doses .

The preliminary conclusion of this section is that increasing ventilation rates throughout the dwelling (turning up the central ventilation unit) does not always lead to lower CO_2- levels in habitable rooms but does result in an unnecessary increase of energy consumption for ventilation.
This applies especially to systems included in the study that have only natural supply and extraction provisions in habitable rooms, as the increased extraction flow rates from wet rooms do not necessarily translate into higher flow rates in the habitable rooms and also because heat recovery is not used.
This applies to a lesser degree to systems that have a mechanical supply and/or extraction component in the habitable rooms. Since increasing flow rates in these systems results directly in higher air throughput in the habitable rooms, this will reduce CO2- excess doses . However, since only a part of the total increase in air flow rates (quotient of surface of habitable room and total habitable room) finds its way to the room in which the CO_2 source volumes are higher, CO2- excess doses cannot always be fully prevented. Moreover, if these systems use heat recovery, the energy wastage as a result of increasing central ventilation flow rates remains limited.

4.3
Results of high and low RH

4.3.1
Number of hours with RH>70%

Figure 4.3.1.1 shows per room the average number of hours per day during which relative humidity is greater than 70%. As expected, this mainly arises in bathrooms and then only for an average of half an hour to two hours a day during the heating season. The exception to this is a dwelling with system X1/A, where the natural air supply is clearly insufficient and could even cause problems with damp.

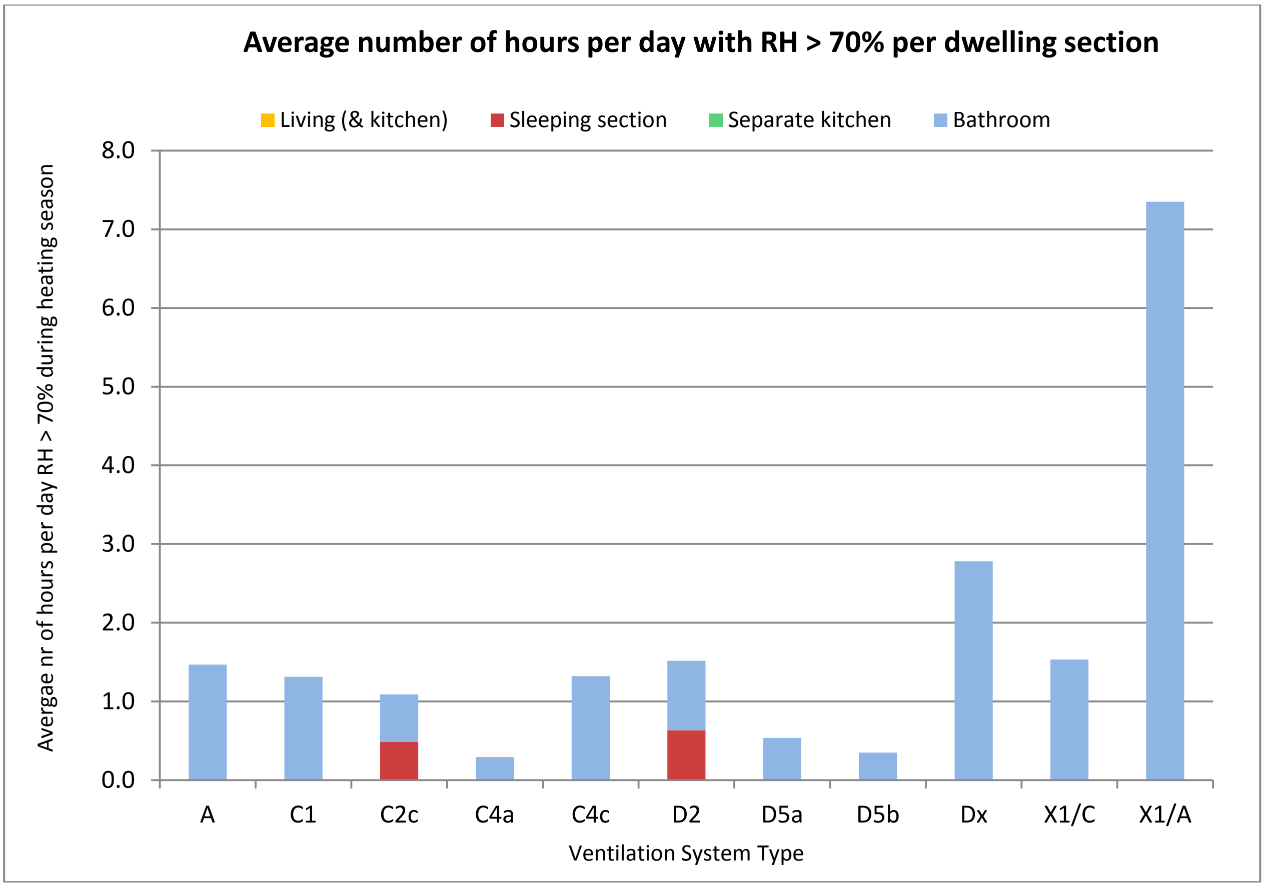


Figure 4.3.1.1: Average number of hours with RH values >70% per part of dwelling during heating season

Higher RH values are also observed in the bedrooms of only two of the 62 homes, and then only for a short period. This could be caused by moisture transport from the bathroom to the bedroom or by drying towels in the bedroom concerned.

Causes of excessive RH values relate to indoor moisture production combined with inadequate ventilation flow rates in the room concerned, or too little throughput of air with a lower RH value. RH values above 70% occur rarely if ever in habitable rooms (living rooms and bedrooms) and kitchens. These values only occur in bathrooms. Moisture production here is significant, given the fact that occupants shower multiple times a week. When relative humidity in the bathroom exceeds 70% for significantly longer than two hours a day, then ventilation flow rates for that room are basically too low. This is indeed the case in a few homes with ventilation system X1/A. In this dwellings, natural extraction in the bathroom is inadequate. In all other dwellings, ventilation rates in the bathroom are adequate.

The graphs below (figure 4.3.1.2) also demonstrate that the correlation between excessive humidity (RH>70%) and the number of occupants possibly present is quite weak. The same goes for the correlation between the average mechanical ventilation rates realised and the number of hours of RH >70%. It is estimated that there is a much stronger correlation between the number of hours of RH >70% and acutely realised ventilation rates (i.e. during moisture production). It can also be deduced that certain aspects of occupant behaviour could have a major impact on hours of RH >70%, as that is the only possible explanation for the distribution in results per individual dwelling. This includes whether or not vent windows / grilles in the bathroom are used, the time and frequency of showering and whether or not the bathroom door is left open after showering.

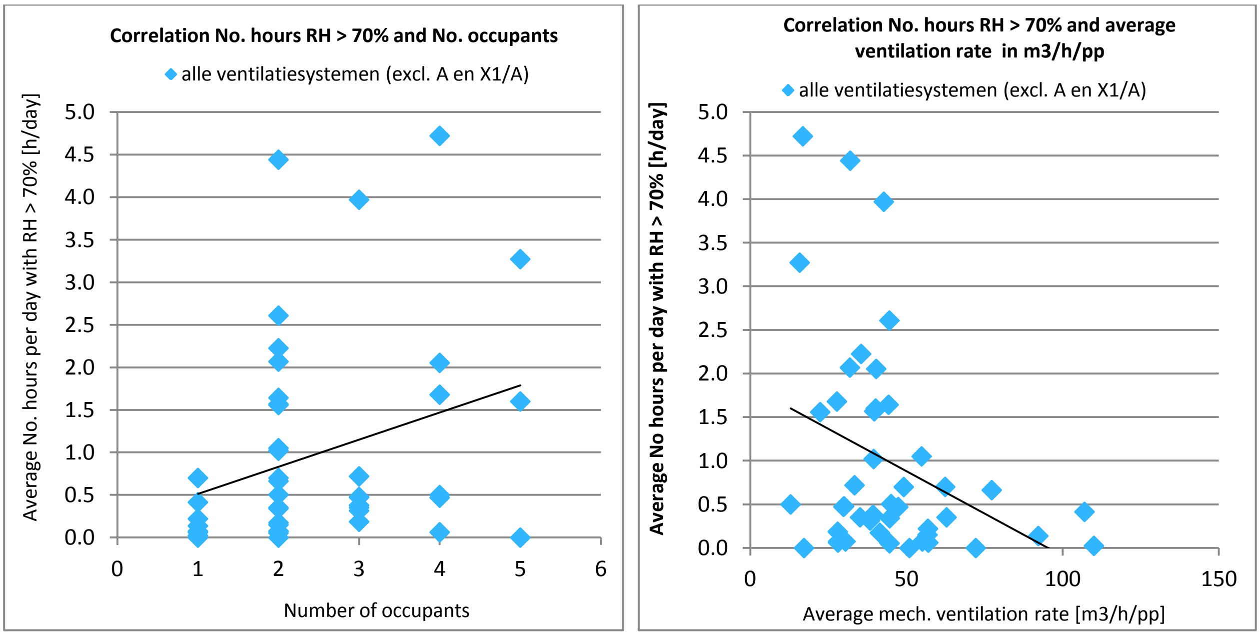
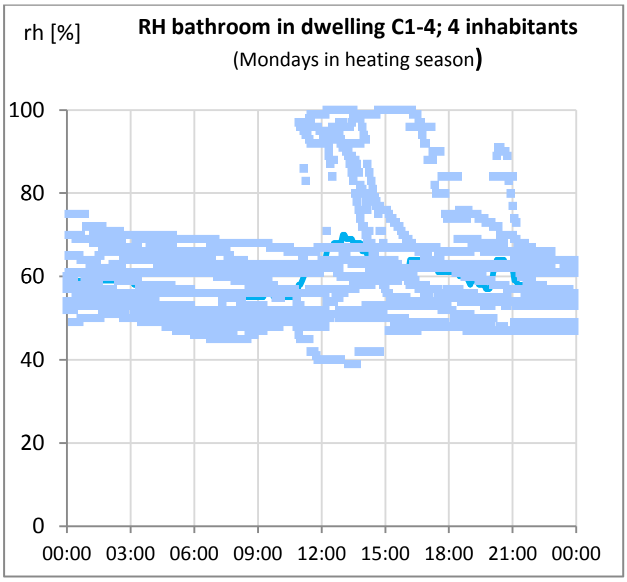
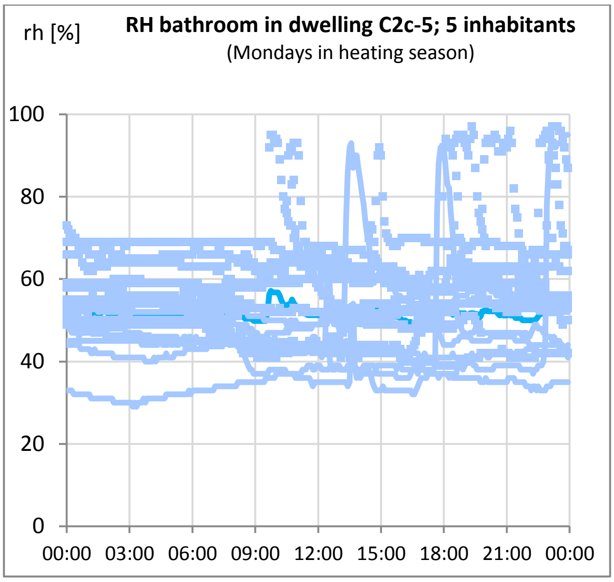


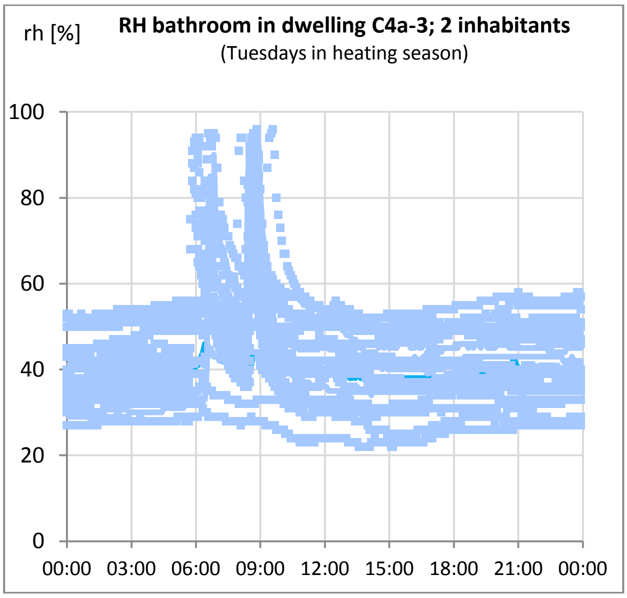
Figure 4.3.1.2: Average number of hours with RH values >70% per dwelling during heating season in relation to number of occupants and the average mechanical ventilation rates per occupant.

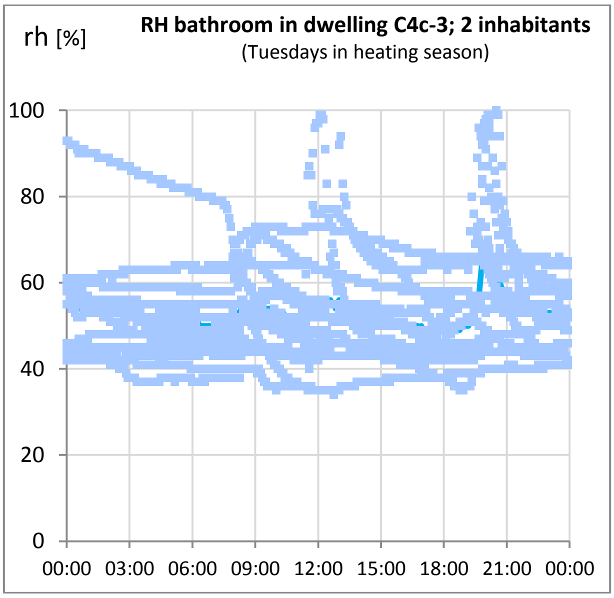
4.3.2
Illustrations of hours RH > 70%

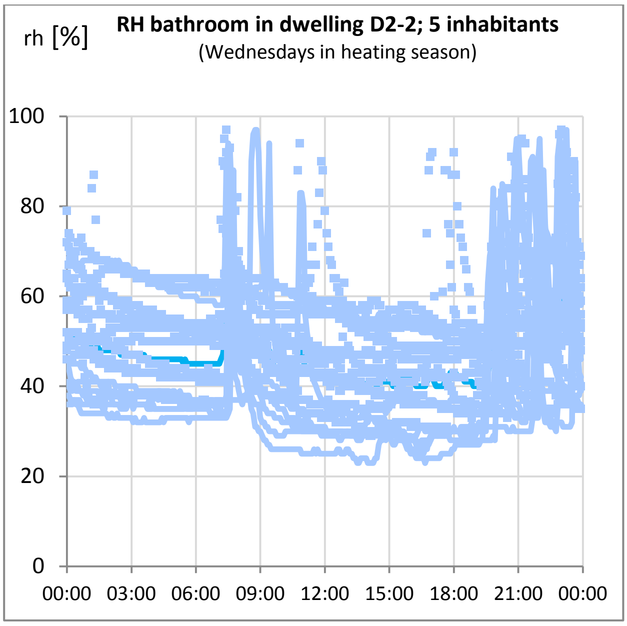
To gain insight into how RH develops in bathrooms with different ventilation systems, the graphs below show for each ventilation system the development of RH on a random day during the heating season.

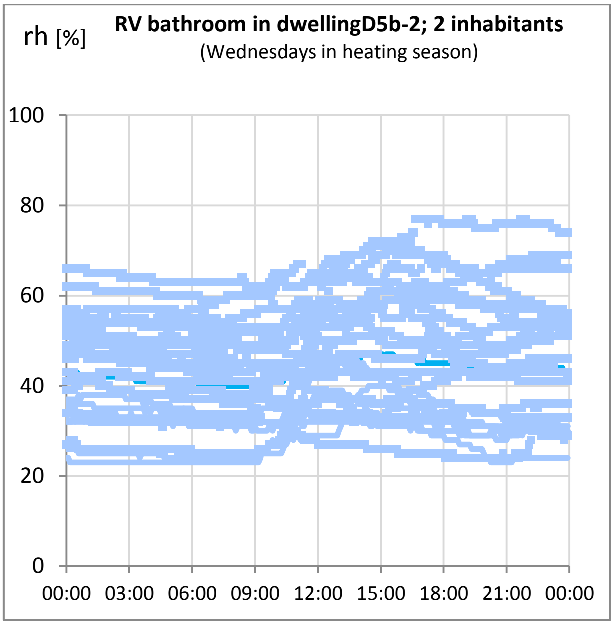

RH bathroom in dwelling C1-4; 4 inhabitants
(Mondays in heating season)

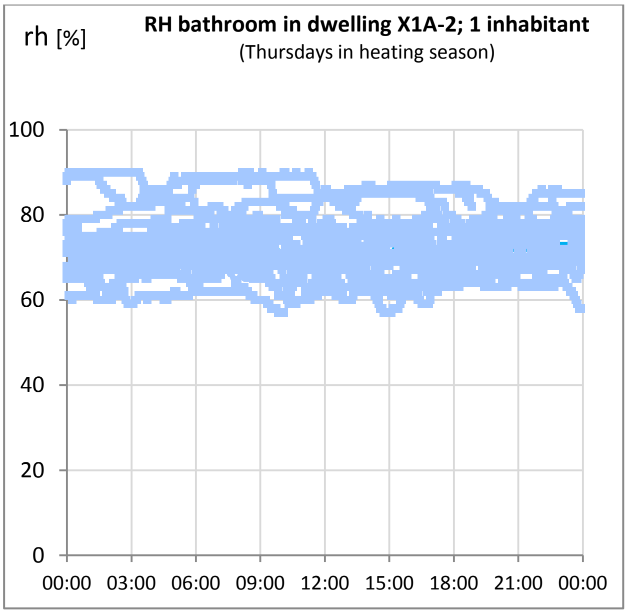

RH bathroom in dwelling C2c-5; 5 inhabitants
(Mondays in heating season)


RH bathroom in dwelling C4a-3; 2 inhabitants
(Tuesdays in heating season)


RH bathroom in dwelling C4c-3; 2 inhabitants
(Tuesdays in heating season)







Dwelling X1A-2 is the only one of 62 homes studied in which RH in the bathroom exceeds 70% for longer periods. This bathroom seems to suffer from continual moisture production and the ventilation rates measured are at the very least below par.

4.3.3
Number of hours with RH<30%

During the heating season, relative humidity in all habitable rooms falls below 30% for several hours a day. Figure 4.3.3.1 shows the number of hours below the lower threshold per part of dwelling. All hours below the lower threshold are given in the graph below, both as an average and in cumulative terms, per group of dwellings. On average the number of hours below this level run from 4 to as many as 10 hours per room. As there are multiple bedrooms per dwelling, it goes without saying that the red part in the histogram below is the largest.

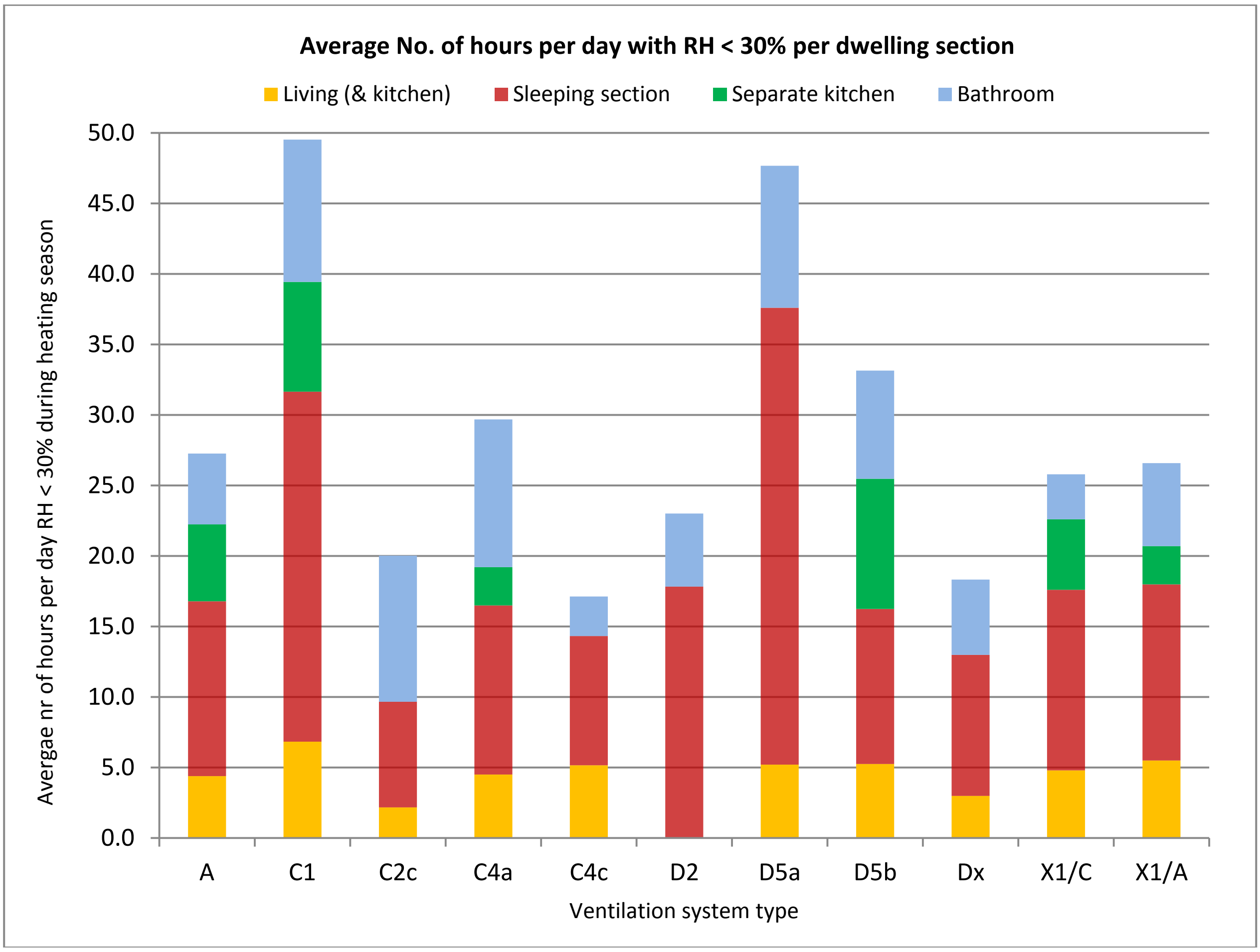
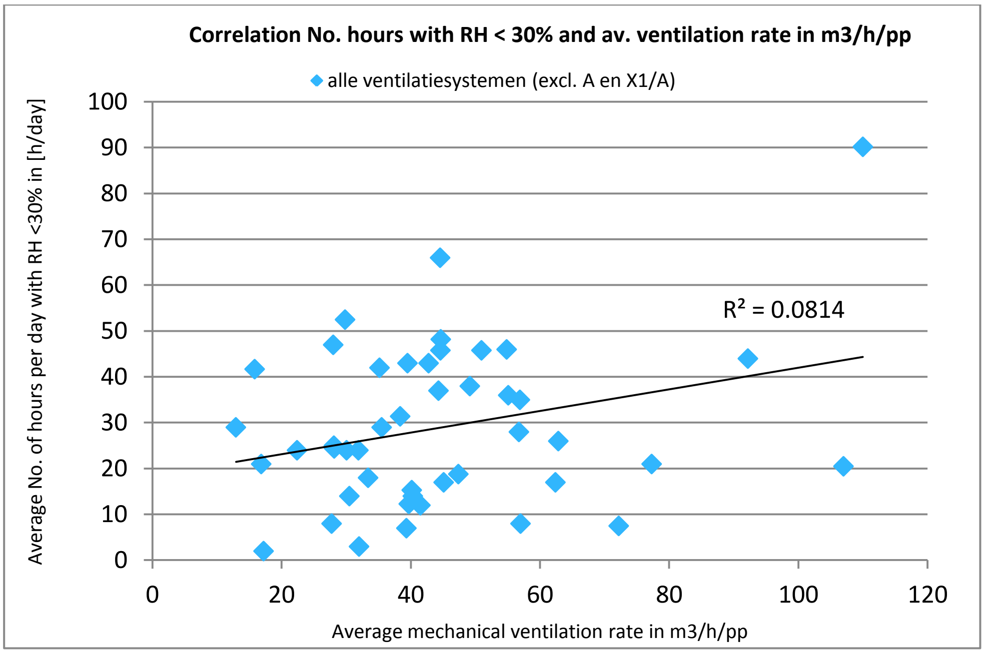


Figure 4.3.3.1: Average number of hours with RH values <30% per part of dwelling during heating season

Humidity below 30% occurs frequently in winter. The colder outdoor air contains little moisture, and when this air is heated to ca. 20°C indoors, its RH can drop to below 30%. Internal moisture production can slightly raise these low RH values indoors.

The graphs below (Figure 4.2.3.2) show that here too the correlation between mechanical ventilation rates and the number of occupants is weak, though identifiable. More ventilation implies a higher number of hours with RH<30%, and more people results in higher moisture production and thus in a lower number of hours with RH<30%

The distribution in the graphs below is mainly suggested by the variation in the number of rooms per dwelling (more rooms per dwelling mean a higher number of hours of RH<30%).
The average value of the number of hours at RH<30% *per room* shows a much tighter distribution.
Hours at RH<30% are structurally present and vary, depending on moisture production and ventilation habits, from an average ca. 5 up to max. ca. 10 hours per day.
Only one dwelling deviates from this picture; this is a home with system D5a with just one occupant (= low moisture production) and fairly high average mechanical ventilation rates of 110m3/h



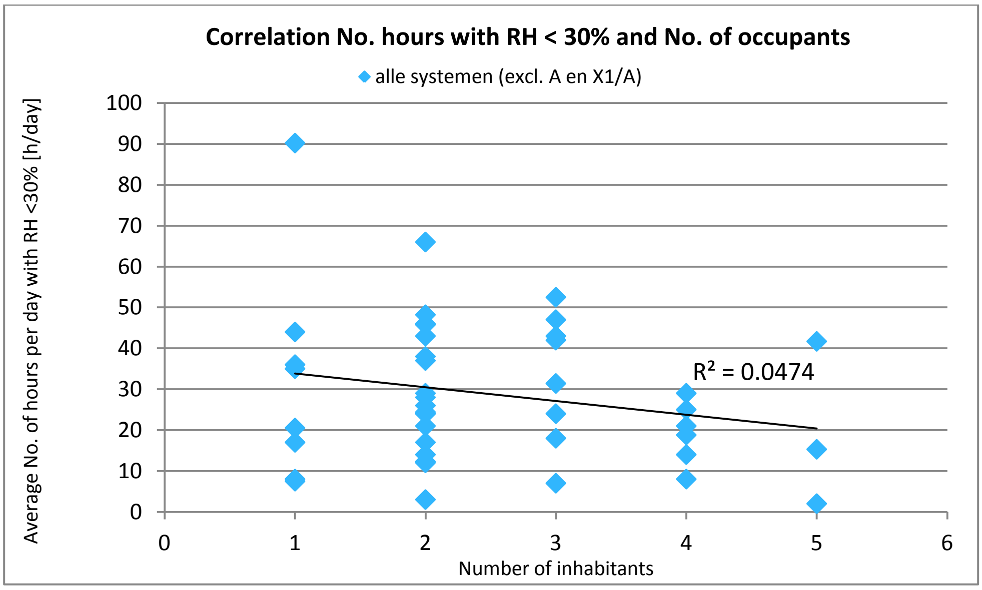


Figure 4.3.3.2: Average number of hours with RH values <30% per dwelling during heating season in relation to number of occupants and the average mechanical ventilation rates per occupant.

4.4 Energy consumption of ventilation systems

4.4.1

Energy consumption

Section 3.4, ‘Indicator of energy efficiency’, shows which method was used to determine the energy efficiency of the ventilation systems studied. In brief, this method involves the following:

- Based on the ventilation rates measured at a given moment and the humidity and temperature of both indoor and outdoor air, determine the thermal energy balance of the air exchanged over an entire heating season: $Q_{th;vent}$, taking account of whether or not heat recovery is used (calculation carried out for heat recovery in line with EN13141-7/8, and for an η assumed overall efficiency in practice of 80%).
- Correct this balance with the system efficiency on HE heating system with limited distributive losses (divide by 85%) to determine the amount of primary energy required: $Q_{th;vent} / 0.85$
- Add to this the total electricity consumption of all ventilation units during the heating season and adjust this for primary energy (divide by 40%): $Q_{elec;vent} / 0.40$
- Divide the sum by the total heated surface area of the dwelling concerned to determine the primary energy consumption per m2 habitable room for the ventilation system concerned in the dwelling with related occupant habits.

Or, in terms of a formula

$$Q_{tot;vent} / m^2 \quad = \left(Q_{th;vent} / 0.85 \; + \; Q_{elec;vent} / 0.40\right) / Ag$$

The table below shows the average results per dwelling of each group of ventilation systems. Ventilation system A cannot be calculated as no mechanical ventilation rates can be measured.

Ventilation system	$Q_{th;vent} / 0.85$ (η conform EN13141-7/8)	$Q_{elec;vent} / 0.40$	$Q_{tot;vent} / m^2$ (η conform EN13141-7/8)	$Q_{tot;vent} / m^2$ (η = 80%)
	[MJ/heat.ssn]	[MJ/heat.ssn]	[MJ/m2/heat.ssn]	[MJ/m2/heat.ssn]
System C1	[1]	[1]	[1]	
System C2c	10494	968	119	119
System C4a	9229	259	144	144
System C4c (with mech.ext. habitable rooms)	7874	977	82	82
System D2	1075	1834	24	40
System D5a	1098	866	18	25
System D5b	6307	417	102	103
System Dx	361	1026	13	23
System X1/C	6467	305	102	104

[1.] Flow rates could not be measured for all dwellings in this group.

Figure 4.4.1.1 Average primary energy consumption per group of ventilation systems

If we compare the results from the last column of Figure 4.4.1, then the following things are striking:

- System C4a with CO_2 control uses more energy than a comparable system without CO_2 control (C2c).
- Central system D uses 75–80% less primary energy than central system C
- Ventilation systems with decentralised heat recovery save less versus central system C. The main cause of this is the fact that the systems in this study (D5b and X1/C) are combined with a permanently running and unregulated central extraction unit (without heat recovery) that runs in the lowest setting. However, the average ventilation flow rates realised by this central extraction unit are still a factor of 5 to 10 higher than the average ventilation rates of the decentralised heat-recovery units. This means the central extraction unit is largely responsible for the primary energy consumption of these systems, yet this unit does not contribute to reducing CO2- excess doses in habitable rooms (after all habitable rooms with decentralised heat recovery do not have any ventilation grilles). In other words, even though decentralised heat recovery units work just fine in terms of energy consumption, ventilation effectiveness and indoor air quality, this effectiveness is not seen in systems that combine them with unregulated and continually running central extraction units in wet rooms.

4.4.2
Energy consumption versus CO2- excess doses

A key aim of the MONICAIR project is to gain greater insight into the IAQ and related energy performance of different ventilation systems. The table below shows the key results on this point.

Ventilation system	**Qtot;vent /m2** (η conform EN13141-7/8)	**Qtot;vent /m2** (η = 80%)	**CO2- excess doses s**	
	[MJ/m2/heat.ssn]	[MJ/m2/heat.ssn]	kppmh/pp/heat.ssn.	Stnrd dev.
System C1	[1]	[1]	349	276
System C2c	119	119	244	216
System C4a	144	144	271	389
System C4c (with mech.ext. habitable rooms)	82	82	72	78
System D2	24	40	68	32
System D5a	18	25	105	156
System D5b	102	103	183	199
System Dx	13	23	76	32
System X1/C	102	104 (8)	175 (30)	139 (33)

1. Flow rates could not be measured for all dwellings in this group.
2. Figures between brackets relate to the performance of decentralised heat-recovery units and connected areas.

Figure 4.4.2.1 Average CO2- excess doses s and primary energy consumption per group of ventilation systems

The graphs below show the results per dwelling, with primary energy consumption per m2 heated surface on the horizontal axis, and excess CO_2 in kppmh per person per heating season on the vertical axis.

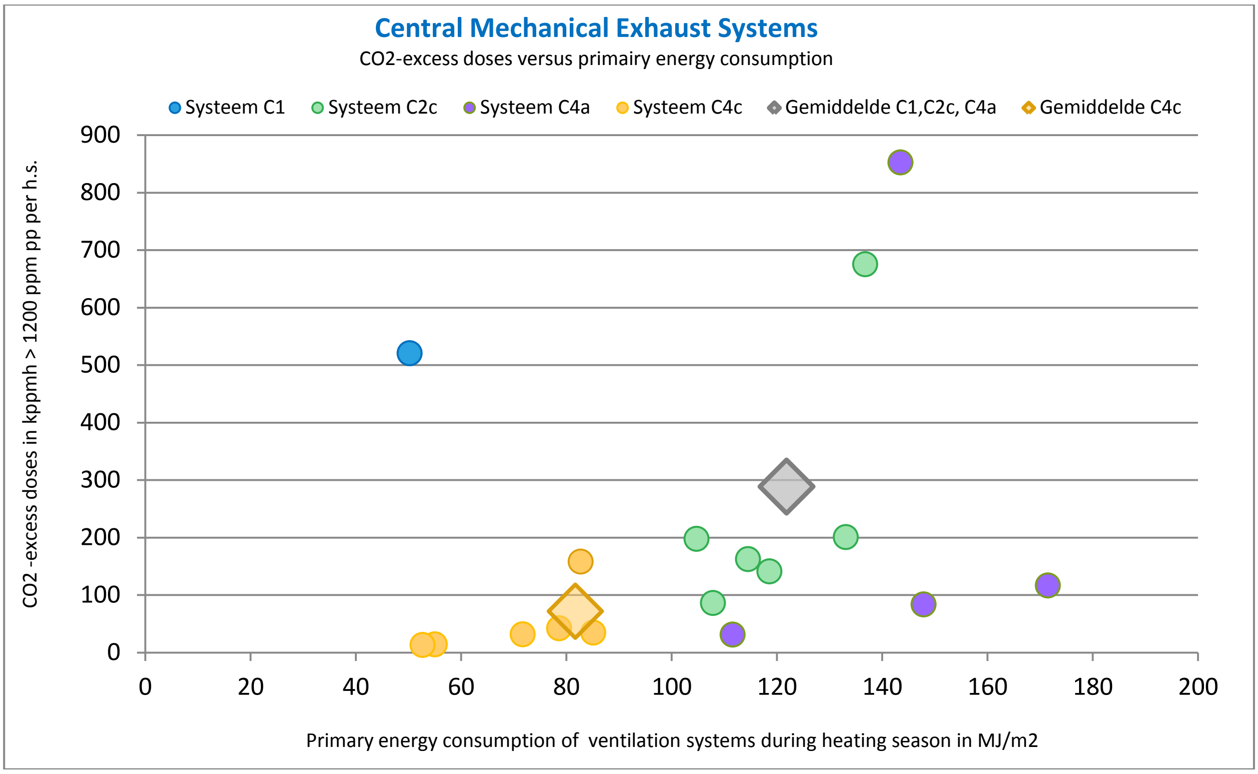


Figure 4.4.2.2 CO2-excess dose versus primary energy consumption of central MV systems

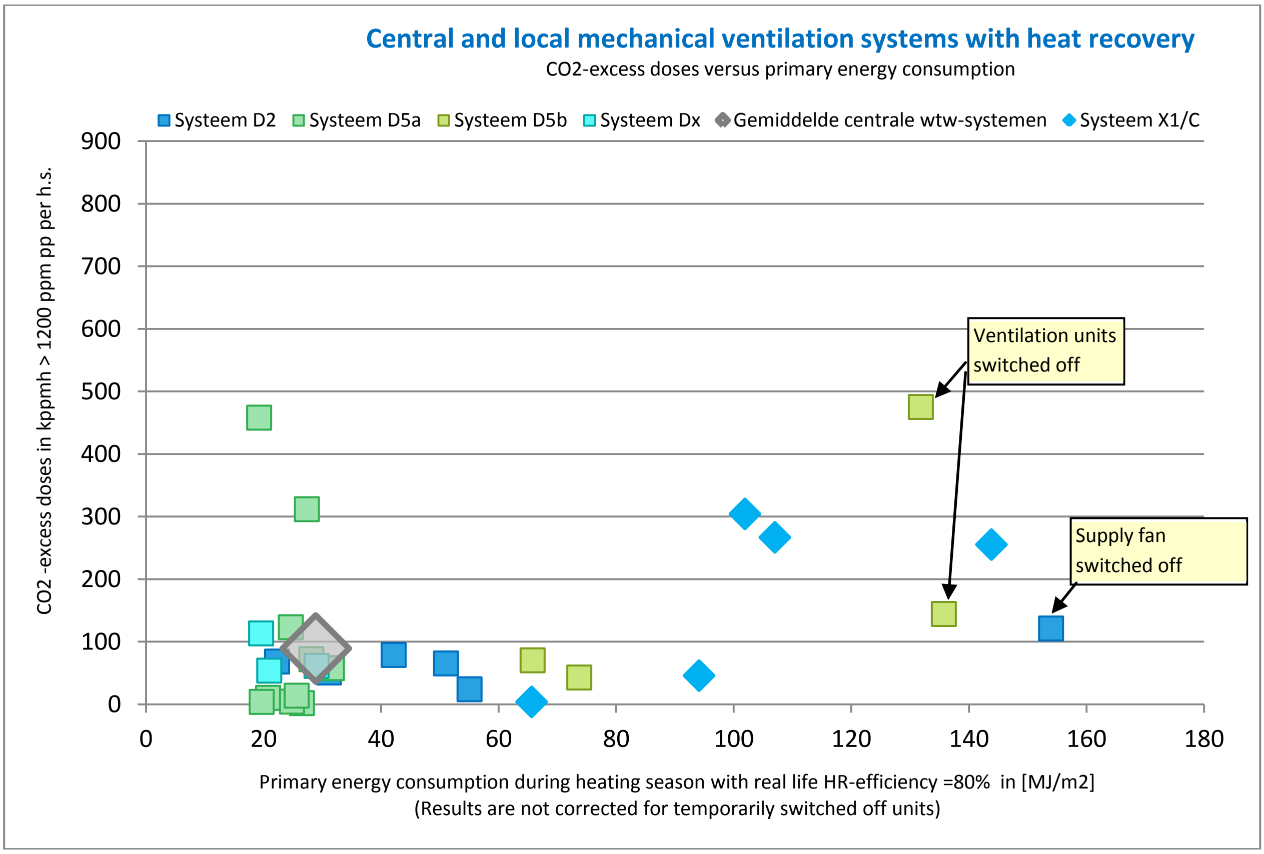


Figure 4.4.2.3 CO2- excess doses versus primary energy consumption of central and local heat-recovery systems

Systems with only natural supply and extraction facilities in habitable rooms (systems C1, C2c and C4a) have an average primary energy consumption of **122** MJ per m2 heated surface area with related average CO2- excess doses of **290** kppmh per person. Dwellings with system C4a (system with CO_2 control) score worse on average – both in terms of energy consumption and CO2- excess doses – than a comparable system without CO_2 control (C2c).

System C4c (i.e. the system variant with mechanical extraction facilities and CO_2 control in each habitable room) score considerably better than other dwellings with system C, with an average of **82** MJ primary energy per m2 and related CO2- excess doses of an average **72** kppmh per person.

Dwellings with central heat-recovery systems (with a practical efficiency of 80%) have an average primary energy consumption of **29** MJ per m2 heated surface area with related average CO2- excess doses of **89** kppmh per person, and thus score better on both energy usage and indoor air quality.

Systems with decentralised heat recovery (D5b and X1/C) score between the two. This is mainly caused by the fact that these hybrid systems use unregulated central extraction units for the wet rooms. This extraction unit is responsible for both the higher primary energy consumption and for the higher excess CO doses in bedrooms.

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5 Conclusions

Conclusions in terms of mechanical ventilation flow rates

1.
For unregulated (i.e. manually operated systems), average ventilation rates in summer are close to flow rates that correspond with setting 1 of the 3-position switch, with the exception of a number of dwellings housing occupants that actively turn ventilation up, down or off. So to a large degree, setting 1 defines the average ventilation rates measured per square meter of living space. In the homes tested, average realised ventilation rates were ca. 1 m^3/h per m^2 heated surface area, which corresponds with ca. 0.4 l/s per m^2 habitable room, or ca. 45% of the capacity requirements in Dutch building regulations.

2.
The average flow rate realised for all ventilation systems and all individual dwellings is well above 35 m3/h per person on average. This means that the ventilation volume per person is basically sufficient to prevent or minimise CO2- excess doses . However, the fact that in practice CO_2- excess doses are detected means that this ventilation volume does not always end up in the habitable rooms with CO_2- excess doses .

3.
Raising total ventilation rates throughout the dwelling (e.g. by turning up the central ventilation unit with the 3-position switch) has little or no effect on CO_2- excess doses in habitable rooms, but does increase energy consumption for ventilation. This applies particularly to systems with only natural air supply and extraction facilities in habitable rooms, as an increase in extraction flow rates in the wet rooms does not by definition translate into an increase in ventilation rates in the habitable room with high CO_2 concentrations. Moreover, heat recovery is not used in these system either. For systems with a mechanical component in habitable rooms, an increase in central ventilation rates does have some effect on CO_2- excess doses , but the higher flow rates in a specific habitable room do not always correspond with the increase of the CO_2 source. Heat recovery further reduces the energy loss from unnecessary ventilation.

4.
Occupant behaviour in dwellings with unregulated (manual) systems is minimal and is more likely to be down to customary ventilation habits than by reactive behaviour, with occupants reacting to poor air quality and increasing ventilation levels using the 3-position switch.
The study demonstrates that CO_2 concentrations can rise to well above 3000 ppm without occupants taking any action.
Habits and customary patterns of behaviour relate to how often the extractor hood and/or 3-position switch of the ventilation system are used during showering and cooking, but also to the use of ventilation grilles and vent windows. There is major variation among occupants on this point.

5.

In dwellings with CO_2 regulated systems, switching behaviour is significantly higher. However, if a CO_2 sensor is not located in a habitable room (but on the landing, for example) or when a CO_2 sensor is not coupled to a mechanical component of the room in which the CO_2 sensor is fitted, this increased switching behaviour does not always lead to lower CO_2- excess doses .

Conclusions on CO_2- excess doses

6.

The CO_2- excess doses of ventilation systems that *comply fully with building regulation requirements* show major differences in practice, both between different individual dwellings with the same ventilation system, and between ventilation systems themselves.

7.

The CO_2- excess doses measured (i.e. levels above >1200 ppm CO_2 multiplied by the length of time this level occurs) for the systems programmed in line with building regulations (systems 2 to 10) vary from *0* to *852* kppmh per person per heating season. This means that during the heating season (with assumed average CO_2- excess doses of 350 ppm and an average occupant-present time of ca. 15 hrs/day) during *0* to ca. *75%* of the time at home, the ventilation is insufficient in the habitable rooms where occupants spend the most time.

8.

The distribution of CO_2- excess doses per ventilation system per heating season increases as supply and extraction facilities are used that depend entirely on natural forces (convection and air-pressure differences) and on occupant behaviour:

Ventilation systems	Number of hours a day with CO_2>1200 ppm	Average excess >1200 ppm CO_2	Average CO_2 excess doses per dwelling per day	Average CO_2 excess doses per dwelling per heating season	Average CO_2excess doses per person per dwelling per heating season with related standard deviation	
	[h/day]	[ppm]	[ppmh/day]	[kppmh/ht.ssn]	[kppmh/pp/ht.ssn]	stndrd dev.
A	9.76	689	6723	1425	442	*438*
C1	10.95	512	5600	1187	349	*276*
C.2c	12.42	344	4267	905	244	*216*
C.4a	7.62	731	5570	1181	271	*389*
C.4c	3.13	247	773	164	72	*78*
D.2	3.52	291	1024	217	68	*32*
D.5a	2.65	494	1308	277	105	*156*
D.x	3.63	199	718	152	76	*32*
D.5b	4.40	509	2239	475	183	*199*
X1/C	6.84 *(1.45)*	320 *(217)*	2186 *(315)*	463 *(67)*	175 *(30)*	*139 (33)*
X1/A	2.82 *(1.27)*	346 *(302)*	976 *(384)*	207 *(81)*	167 *(61)*	*124 (47)*
Figures between brackets relate to the performance of decentralised heat-recovery units in living rooms and connected areas						

Table 5.1. Average CO_2- excess doses >1200 ppm per group of ventilation systems

Note: The CO_2- excess doses calculated here and the excess dose per person are lower than the excess that actually occurred, as the calculation method used does not take account of the fact that multiple individuals may be exposed to the same CO_2- excess doses in a room (main bedroom, living room). As a rule, if the total dose of exposure time to excess levels is divided by the number of occupants, this results in an excessively low value. Please take account of this when interpreting the results.

9.
The CO_2- excess doses occur mainly in bedrooms, and to a lesser degree in living rooms and separate kitchens (if present).

10.
Systems with mechanical supply and/or extraction components in the bedrooms show lower CO_2- excess doses there than systems with natural supply and extraction facilities in the bedrooms.

11.
Systems that use CO_2 sensors not linked to a mechanical supply and/or extraction component in the habitable room in which the sensor takes its measurements, do not always show better indoor air quality (lower CO_2- excess doses) than the same systems without a CO_2 sensor (compare results for system C.4a with CO_2 sensor and system C.2c without CO_2 sensor).

Also, systems with the CO_2 sensor mounted outside of a habitable room in a connecting space, and whereby ventilation volumes in the adjacent habitable rooms are regulated by air transport via overflow components, do not show better indoor air quality than the same systems without a CO_2 sensor (compare bedrooms of D.5a with D.2).

12.
In terms of realised indoor air quality, ventilation systems that use only natural supply and/or extraction facilities in habitable rooms show a greater dependency on the number of occupants than systems with a mechanical supply and/or extraction component in the habitable rooms.

13.
The air-tightness of the dwelling appears to have little or no effect on the realised indoor air quality.

Conclusions on exceeding RH high-limit / low-limit

14.
Periods with excessively high humidity (RH >70%) occur almost exclusively in bathrooms and are as a rule slightly shorter than 2 hours a day on average. The exception to this is a single dwelling with natural extraction facilities in the wet rooms (system X1/A).

15.
Periods with low humidity during the heating season (RH <30%) occur structurally in all rooms, and depending on internal moisture production and ventilation behaviour vary from an average of ca 5 hours to a maximum of 10 hours per day per room.

Conclusions on energy consumption of ventilation systems

16.
Systems with only natural supply and extraction facilities in habitable rooms (systems C1, C2c and C4a) have an average primary energy consumption of **122** MJ per m2 heated surface area with related average CO2- excess doses of **290** kppmh per person. Dwellings with system C4a (system with CO_2 control) score worse on average – both in terms of energy consumption and CO2- excess doses – than a comparable system without CO_2 control (C2c).

17.
System C4c (i.e. the system variant with mechanical extraction facilities and CO_2 control in each habitable room) score considerably better than other dwellings with system C, with an average of **82** MJ primary energy per m2 and related CO2- excess doses of an average **72** kppmh per person.

18.
Dwellings with central heat-recovery systems (with a practical efficiency of 80%) have an average primary energy consumption of **29** MJ per m2 heated surface area with related average CO2- excess doses of **89** kppmh per person, and thus score better on both energy usage and indoor air quality.

19.
Systems with decentralised heat recovery (D5b and X1/C) score between the two. This is mainly caused by the fact that these hybrid systems use unregulated central extraction units for the wet rooms. This extraction unit is responsible for both the higher primary energy consumption and the higher CO2- excess doses s in the bedrooms of dwellings with system X1/C.

APPENDICES

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APPENDIX I

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APPENDIX II

Data tables

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DATASHEET DWELLINGS

Ventilation System Type	Anonym. address	Dwelling type	Nr of hab. rooms (incl combined living/kitchen)	Nr. of seperated wet rooms (bath/kitch.)	Type of kitchen hood	Surface heated living area	Air tightness qv10	Nr. of inhabitants
		1 = tussenw. 2 = hoekw. 3 = 2ond1kap 4 = portiekw			0 = no 1 = mech exh 2 = recycling 3 = motorloos			
		[-]	[-]	[-]		[m2]	[l/s/m2]	[-]
A	**TOTAL AVERAGES**		3.80	2.00		75.62	2.66	2.40
	STANDARD DEVIATION		0.45	0.00		13.71	1.18	1.14
	A-1	4	3	2	?	56.13	1.568	1
	A-2	1	4	2	1	66.07	1.242	2
	A-3	2	4	2	3	85.30	3.082	4
	A-4	1	4	2	3	85.30	3.713	3
	A-5	1	4	2	1	85.30	3.713	2
C1	**TOTAL AVERAGES**		3.67	2.00		90.06	1.97	2.83
	STANDARD DEVIATION		0.82	0.00		24.12	0.73	1.17
	C1-1	2	3	2	?	70.00	2.637	1
	C1-2	2	3	2	?	68.00	2.637	2
	C1-3	1	3	2	?	70.00	2.637	3
	C1-4	1	4	2	1	103.36	1.312	4
	C1-5	1	4	2	?	103.36	1.312	3
	C1-6	2	5	2	?	125.62	1.312	4
C.2c	**TOTAL AVERAGES**		4.33	1.00		96.12	1.00	3.33
	STANDARD DEVIATION		0.52	0.00		0.00	0.00	1.37
	C2c-1	1	4	1	3	96.12	1.003	1
	C2c-2	1	4	1	1	96.12	1.003	3
	C2c-3	1	4	1	1	96.12	1.003	4
	C2c-4	2	4	1	1	96.12	1.003	3
	C2c-5	2	5	1	1	96.12	1.003	5
	C2c-6	1	5	1	3	96.12	1.003	4
C.4a	**TOTAL AVERAGES**		3.75	2.00		66.07	1.24	2.75
	STANDARD DEVIATION		0.50	0.00		0.00	0.00	1.50
	C4a-1	1	4	2	1	66.07	1.242	2
	C4a-2	2	4	2	1	66.07	1.242	2
	C4a-3	1	3	2	1	66.07	1.242	2
	C4a-5	1	4	2	1	66.07	1.242	5
TOTAL AVERAGE C1, C2c, C4a			3.94	1.63		86.33	1.43	3.00
OVERALL STANDARD DEVIATION			0.68	0.50		18.64	0.61	1.26
C.4c	**TOTAL AVERAGES**		3.57	1.00		108.33	1.44	1.50
	STANDARD DEVIATION		0.53	0.00		0.00	0.00	0.76
	C4c-1	2	4	1	0	108.33	1.440	1
	C4c-2	1	3	1	0	108.33	1.440	1
	C4c-3	1	4	1	0	108.33	1.440	2
	C4c-4	1	3	1	0	108.33	1.440	2
	C4c-5	2	3	1	0	108.33	1.440	1
	C4c-6a	2	4	1	0	108.33	1.440	2
	C4c-6b	2	4	1	0	108.33	1.440	3
D2	**TOTAL AVERAGES**		4.00	1.00		119.31	0.60	3.33
	STANDARD DEVIATION		0.00	0.00		24.42	0.00	1.21
	D2-1	3	4	1	1	139.86	0.602	2
	D2-2	3	4	1	1	110.53	0.602	5
	D2-3	3	4	1	1	135.63	0.602	2
	D2-4	3	4	1	1	146.01	0.602	4
	D2-5	1	4	1	1	91.9	0.602	4
	D2-6	1	4	1	1	91.9	0.602	3
D5a	**TOTAL AVERAGES**		4.40	1.00		110.04	0.56	2.20
	STANDARD DEVIATION		0.52	0.00		14.77	0.40	0.79
	D5a-1	1	4	1	1	92.92	0.826	1
	D5a-2	3	4	1	1	119.85	0.854	2
	D5a-3	3	4	1	1	92.92	0.625	2
	D5a-4	1	4	1	1	92.92	1.283	3
	D5a-5	3	4	1	1	92.92	0.826	2
	D5a-6	3	4	1	1	119.85	0.625	3
	D5a-7	2	5	1	3	122.26	0.150	2
	D5a-8	1	5	1	3	122.26	0.150	3
	D5a-9	1	5	1	2	122.26	0.150	3
	D5a-10	1	5	1	2	122.26	0.150	1
D5b	**TOTAL AVERAGES**		3.00	2.00		66.07	1.24	2.00
	STANDARD DEVIATION		0.00	0.00		0.00	0.00	0.82
	D5b-1	2	3	2	1	66.07	1.242	3
	D5b-2	1	3	2	1	66.07	1.242	2
	D5b-3	2	3	2	0	66.07	1.242	1
	D5b-4	1	3	2	1	66.07	1.242	2
Dx	**TOTAL AVERAGES**		4.00	1.00		108.33	1.14	2.00
	STANDARD DEVIATION		0.00	0.00		0.00	0.00	0.00
	Dx-1	1	4	1	?	108.33	1.138	2
	Dx-2	2	4	1	?	108.33	1.138	2
	Dx-3	2	4	1	1	108.33	1.138	2
TOTAL AVERAGES D2, D5a, Dx			4.21	1.00		112.70	0.67	2.53
OVERALL STANDARD DEVIATION			0.42	0.00		17.21	0.35	1.02
X1/C	**TOTAL AVERAGES**		4.00	2.00		66.07	1.24	2.20
	STANDARD DEVIATION		0.00	0.00		0.00	0.00	1.10
	X1C-1	1	4	2	1	66.07	1.242	4
	X1C-2	1	4	2	1	66.07	1.242	2
	X1C-3	2	4	2	1	66.07	1.242	2
	X1C-4	1	4	2	1	66.07	1.242	1
	X1C-5	2	4	2	1	66.07	1.242	2
X1/A	**TOTAL AVERAGES**		3.00	2.00		56.13	1.57	1.75
	STANDARD DEVIATION		0.00	0.00		0.00	0.00	0.96
	X1A-#	4	3	2	?	56.13	1.568	3
	X1A-1	4	3	2	?	56.13	1.568	1
	X1A-2	4	3	2	?	56.13	1.568	2
	X1A-3	4	3	2	1	56.13	1.568	1
TOTAL AVERAGES X1/C, X1/A			3.56	2.00		61.65	1.39	2.00
OVERALL STANDARD DEVIATION			0.53	0.00		5.24	0.17	1.00

DATASHEET CO2-OVERSCHRIJDING

Gemiddeld aantal CO2-overschrijdingsuren per dag >1200 ppm gedurende het stookseizoen

(Gemiddeld aantal uren per dag dat de CO2-concentratie boven de 1200 ppm is)

gemiddelde aanwezigheid in uren/pp/dag: **15**

Woning/ventilatiesysteem	inw.	overschrijding in gemiddeld aantal uren/dag >1200 ppm [h/dag]										als % van de pp aanwezige tijd			
		slaapvertrekken				woonsecties				totale woning		totale woning	slaapkmrs	wnkmr/keuken	sep. keuken
		zolder	slpkmr 3	slpkmr 2	slpkmr 1	totaal slaap	keuken	woonkamer	woonkeuken	totaal uren	gem. uren/pp				
A-1	1			0.41	0.09	0.50	0.87	0.66		2.03	2.03	13.53%	3.33%	4.40%	5.80%
A-2	2		0.03	0.00	0.13	0.16	3.47	3.78		7.41	3.71	24.70%	0.53%	12.60%	11.57%
A-3	4		6.34	10.65	4.20	21.19	3.27	4.22		28.68	7.17	47.80%	35.32%	7.03%	5.45%
A-4	3		0.14	4.48	1.20	5.82	2.22	2.02		10.06	3.35	22.36%	12.93%	4.49%	4.93%
A-5	2			0.05	0.16	0.21	0.19	0.23		0.63	0.32	2.10%	0.70%	0.77%	0.63%
totaal gemiddeld	2.40		2.17	3.12	1.16	5.58	2.00	2.18		9.76	3.31	22.10%	10.56%	5.86%	5.68%
totaal gemiddeld per persoon			*0.41*	*0.92*	*0.34*	*1.58*	*0.85*	*0.88*	*0.00*	*3.31*					
C1-1	1			0.00	0.38	0.38	0.00	0.01		0.39	0.39	2.60%	2.53%	0.07%	0.00%
C1-2	2			2.08	2.29	4.37	3.45	3.49		11.31	5.66	37.70%	14.57%	11.63%	11.50%
C1-3	3			0.17	0.74	0.91	0.06	0.05		1.02	0.34	2.27%	2.02%	0.11%	0.13%
C1-4	4		4.93	0.14	8.34	13.41	0.76	0.84		15.01	3.75	25.02%	22.35%	1.40%	1.27%
C1-5	3		0.40	5.85	0.05	6.30	5.69	5.55		17.54	5.85	38.98%	14.00%	12.33%	12.64%
C1-6	4		0.57	11.29	5.10	16.96	1.83	1.62		20.41	5.10	34.02%	28.27%	2.70%	3.05%
totaal gemiddeld	2.83		1.97	3.26	2.82	7.06	1.97	1.93		10.95	3.51	23.43%	13.96%	4.71%	4.77%
totaal gemiddeld per persoon			*0.25*	*0.98*	*0.86*	*2.09*	*0.71*	*0.71*		*3.51*					
C2c-1	1		0.00	0.00	0.87	0.87			0.56	1.43	1.43	9.53%	5.80%	3.73%	
C2c-2	3		1.51	1.44	2.70	5.65			1.35	7.00	2.33	15.56%	12.56%	3.00%	
C2c-3	4		1.42	0.90	3.90	6.22			2.51	8.73	2.18	14.55%	10.37%	4.18%	
C2c-4	3		4.03	4.25	1.20	9.48			0.65	10.13	3.38	22.51%	21.07%	1.44%	
C2c-5	5	0.03	5.89	2.05	0.97	8.94			4.26	13.20	2.64	17.60%	11.92%	5.68%	
C2c-6	4	7.07	11.73	3.48	6.32	28.60			5.43	34.03	8.51	56.72%	47.67%	9.05%	
totaal gemiddeld	3.33	3.55	4.10	2.02	2.66	9.96			2.46	12.42	3.41	22.74%	18.23%	4.52%	
totaal gemiddeld per persoon		*0.30*	*1.05*	*0.57*	*0.82*	*2.73*			*0.68*	*3.41*					
C4a-1	2		0.25	0.01	0.02	0.28	0.26	0.22		0.76	0.38	2.53%	0.93%	0.73%	0.87%
C4a-2	2		0.01	0.17	0.01	0.19	1.16	1.55		2.90	1.45	9.67%	0.63%	5.17%	3.87%
C4a-3	2			0.15	0.01	0.16	0.00	3.00		3.16	1.58	10.53%	0.53%	10.00%	0.00%
C4a-4	5		0.55	10.38	10.26	21.19	2.47	0.00		23.66	4.73	31.55%	28.25%	0.00%	3.29%
totaal gemiddeld	2.75		0.27	2.68	2.58	5.46	0.97	1.19		7.62	2.04	13.57%	7.59%	3.98%	2.01%
totaal gemiddeld per persoon			*0.06*	*0.56*	*0.52*	*1.14*	*0.30*	*0.60*		*2.04*					
Gewogen gemiddelde C1,C2c, C4a	**3.00**	**3.55**	**2.61**	**2.65**	**2.70**		**1.57**	**1.94**		**10.67**	**3.11**	**20.71%**	**13.97%**	**4.45%**	**2.29%**
C4c-1	1		0.05	0.00	0.05	0.10			0.29	0.39	0.39	2.60%	0.67%	1.93%	
C4c-2	1			0.36	0.05	0.41			0.33	0.74	0.74	4.93%	2.73%	2.20%	
C4c-3	2		0.01	1.15	0.34	1.50			4.20	5.70	2.85	19.00%	5.00%	14.00%	
C4c-4	2			0.15	0.05	0.20			0.83	1.03	0.52	3.43%	0.67%	2.77%	
C4c-5	1			0.02	0.28	0.30			0.28	0.58	0.58	3.87%	2.00%	1.87%	
C4c-6a	2		0.00	0.15	0.00	0.15			1.12	1.27	0.64	4.23%	0.50%	3.73%	
C4c-6b	3		0.21	5.76	5.88	11.85			0.36	12.21	4.07	27.13%	26.33%	0.80%	
totaal gemiddeld	1.71		0.07	1.08	0.95	2.07			1.06	3.13	1.40	9.31%	5.41%	3.90%	
totaal gemiddeld per persoon			*0.02*	*0.43*	*0.36*	*0.81*			*0.59*	*1.40*					
D2-1	2		1.90	0.02	0.04	1.96			0.36	2.32	1.16	7.73%	6.53%	1.20%	
D2-2	5		0.03	0.37	2.41	2.81			0.98	3.79	0.76	5.05%	3.75%	1.31%	
D2-3	2		0.77	0.12	0.11	1.00			0.24	1.24	0.62	4.13%	3.33%	0.80%	
D2-4	4		2.17	0.11	0.28	2.56			1.82	4.38	1.10	7.30%	4.27%	3.03%	
D2-5	4		0.02	2.81	0.78	3.61			1.00	4.61	1.15	7.68%	6.02%	1.67%	
D2-6	3		0.01	0.96	3.09	4.06			0.74	4.80	1.60	10.67%	9.02%	1.64%	
totaal gemiddeld	3.33		0.82	0.73	1.12	2.67			0.86	3.52	1.06	7.10%	5.49%	1.61%	
totaal gemiddeld per persoon			*0.32*	*0.20*	*0.31*	*0.82*			*0.24*	*1.06*					
D5a-1	1		0.00	0.00	0.02	0.02			0.05	0.07	0.07	0.47%	0.13%	0.33%	
D5a-2	2		0.02	0.39	0.00	0.41			0.26	0.67	0.34	2.23%	1.37%	0.87%	
D5a-3	2		0.04	2.32	0.01	2.37			0.08	2.45	1.23	8.17%	7.90%	0.27%	
D5a-4	3		0.00	2.96	0.15	3.11			0.03	3.14	1.05	6.98%	6.91%	0.07%	
D5a-5	2		5.08	0.00	0.05	5.13			0.37	5.50	2.75	18.33%	17.10%	1.23%	
D5a-6	3		8.68	0.33	0.67	9.68			0.21	9.89	3.30	21.98%	21.51%	0.47%	
D5a-7	2	0.20	0.04	0.00	0.00	0.24			0.03	0.27	0.14	0.90%	0.80%	0.10%	
D5a-8	3	0.64	0.00	0.02	0.01	0.67			0.31	0.98	0.33	2.18%	1.49%	0.69%	
D5a-9	3	0.66	0.70	1.09	0.00	2.45			0.94	3.39	1.13	7.53%	5.44%	2.09%	
D5a-10	2	0.00	0.00	0.01	0.00	0.01			0.13	0.14	0.07	0.47%	0.03%	0.43%	
totaal gemiddeld	2.30	0.38	1.46	0.71	0.09	2.41			0.24	2.65	1.04	6.92%	6.27%	0.65%	
totaal gemiddeld per persoon		*0.05*	*0.57*	*0.28*	*0.03*	*0.94*			*0.10*	*1.04*					
D5b-1	3			5.65	1.37	7.02	0.55	2.18		9.75	3.25	21.67%	15.60%	4.84%	1.22%
D5b-2	2			1.07	0.57	1.64	0.84	0.67		3.15	1.58	10.50%	5.47%	2.23%	2.80%
D5b-3	1			0.00	0.35	0.35	0.29	0.02		0.66	0.66	4.40%	2.33%	0.13%	1.93%
D5b-4	2			0.48	0.51	0.99	0.35	2.71		4.05	2.03	13.50%	3.30%	9.03%	1.17%
totaal gemiddeld	2.00			1.80	0.70	2.50	0.51	1.40		4.40	1.88	12.52%	6.68%	4.06%	1.78%
totaal gemiddeld per persoon				*0.66*	*0.34*	*1.00*	*0.27*	*0.61*		*1.88*					
Dx-1	2		0.00	0.37	2.04	2.41			2.98	5.39	2.70	17.97%	8.03%	9.93%	
Dx-2	2		0.12	0.00	0.21	0.33			2.83	3.16	1.58	10.53%	1.10%	9.43%	
Dx-3	2		0.00	0.00	0.00	0.00			2.35	2.35	1.18	7.83%	0.00%	7.83%	
totaal gemiddeld	2.00		0.04	0.12	0.75	0.91			2.72	3.63	1.82	12.11%	3.04%	9.07%	
totaal gemiddeld per persoon			*0.02*	*0.06*	*0.38*	*0.46*			*1.36*	*1.82*					
Gewogen gemiddelde D2, D5a, Dx	**2.58**	**0.38**	**1.03**	**0.63**	**0.52**				**0.83**	**3.08**	**1.17**	**7.80%**	**5.51%**	**2.28%**	
X1C-1	4		0.68	0.16	6.60	7.44	1.13	3.53		12.10	3.03	20.17%	12.40%	5.88%	1.88%
X1C-2	2		0.02	0.41	0.01	0.44	0.01	0.02		0.47	0.24	1.57%	1.47%	0.07%	0.03%
X1C-3	2		0.29	6.99	0.72	8.00	1.63	3.45		13.08	6.54	43.60%	26.67%	11.50%	5.43%
X1C-4	1		0.07	0.73	0.01	0.81	0.10	0.22		1.13	1.13	7.53%	5.40%	1.47%	0.67%
X1C-5	2		0.12	2.75	3.84	6.71	0.67	0.02		7.40	3.70	24.67%	22.37%	0.07%	2.23%
totaal gemiddeld	2.20		0.24	2.21	2.24	4.68	0.71	1.45		6.84	2.93	19.51%	13.66%	3.80%	2.05%
totaal gemiddeld per persoon			*0.09*	*1.17*	*0.79*	*2.05*	*0.31*	*0.57*		*2.93*					
X1A-1	1			0.00	1.42	1.42	0.23	0.00		1.65	1.65	11.00%	9.47%	0.00%	1.53%
X1A-2	2			0.38	0.00	0.38	0.60	3.02		4.00	2.00	13.33%	1.27%	10.07%	2.00%
X1A-3	1			0.47	0.39	0.86	1.15	0.80		2.81	2.81	18.73%	5.73%	5.33%	7.67%
totaal gemiddeld	1.33			0.28	0.60	0.89	0.66	1.27		2.82	2.15	14.36%	5.49%	5.13%	3.73%
totaal gemiddeld per persoon				*0.22*	*0.60*	*0.82*	*0.56*	*0.77*		*2.15*					
Gewogen gemiddelde X1/C & X1/A			**0.24**	**1.49**	**1.62**	**3.26**	**0.69**	**1.38**		**5.33**	**2.64**	**17.58%**	**10.60%**	**4.30%**	**2.68%**

DATASHEET CO2-OVERSCHRIJDING

Gemiddelde hoogte van de CO2-overschrijding in ppm >1200

(Gemiddelde waarde waarmee de grens van 1200 ppm CO2 gedurende het stookseizoen wordt overschreden in ppm)

Woning/ventilatiesysteem	aantal inw.	gemiddelde waarde > 1200 ppm CO2 [ppm]									
		slaapvertrekken				woonsecties				totale woning	
		zolder	slpkmr 3	slpkmr 2	slpkmr 1	totaal slaap	keuken	wnkmr	woonkeuken	gem. per VR	gem. PP
A-1	1			307	67	264	234	138			
A-2	2		133	0	146	144	396	387			
A-3	4		781	747	345	678	656	545			
A-4	3		279	1166	304	967	1327	1401			
A-5	2			120	163	152	200	204			
A-totaal gemiddeld	**2.4**		**767**	**854**	**323**	**724**	**669**	**617**		**689**	**629**
C1-1	1			0	242	242	0	100			
C1-2	2			116	168	143	403	407			
C1-3	3			35	368	305	217	80			
C1-4	4		1215	1164	889	1012	163	124			
C1-5	3		578	193	260	218	396	456			
C1-6	4		261	602	415	535	209	228			
C1-totaal gemiddeld	**2.83**		**1080**	**427**	**609**	**591**	**353**	**383**		**512**	**468**
C2c-1	1		0	0	270	270			307		
C2c-2	3		252	230	447	340			281		
C2c-3	4		451	213	302	323			259		
C2c-4	3		297	283	191	277			326		
C2c-5	5	198	432	135	192	337			388		
C2c-6	4	186	578	450	231	389			298		
C.2c-totaal gemiddeld	**3.33**	**186**	**470**	**294**	**282**	**350**			**317**	**344**	**337**
C4a-1	2		668	100	50	604	262	241			
C4a-2	2		0	576	100	521	311	211			
C4a-3	2			367	0	344	0	347			
C4a-4	5		175	1061	796	910	334	0			
C.4a-totaal gemiddeld	**2.75**		**325**	**1043**	**793**	**899**	**322**	**298**		**731**	**627**
Gemiddelde C1,C2c, C4a	**3.00**	**192**	**409**	**345**	**308**	**423**	**229**	**219**	**310**	**529**	**477**
C4c-1	1		340	0	120	230			134		
C4c-2	1			147	120	144			424		
C4c-3	2		100	108	124	111			317		
C4c-4	2			160	80	140			393		
C4c-5	1			100	107	107			107		
C4c-6a	2		0	87	0	87			254		
C4c-6b	3		200	277	211	243			183		
C.4c-totaal gemiddeld	**1.71**		**222**	**238**	**200**	**220**			**299**	**247**	**243**
D2-1	2		205	100	175	203			236		
D2-2	5		100	143	112	116			247		
D2-3	2		595	208	955	588			238		
D2-4	4		226	164	121	212			381		
D2-5	4		50	206	250	214			717		
D2-6	3		100	301	373	355			372		
D.2-totaal gemiddeld	**3.33**		**274**	**220**	**263**	**255**			**403**	**291**	**303**
D5a-1	1		0	0	150	150			120		
D5a-2	2		50	131	0	127			131		
D5a-3	2		350	221	100	222			163		
D5a-4	3		0	326	387	329			67		
D5a-5	2		558	0	100	554			251		
D5a-6	3		726	115	146	665			214		
D5a-7	2	160	100	0	0	150			100		
D5a-8	3	252	0	150	100	246			113		
D5a-9	3	467	599	483	0	511			523		
D5a-10	2	0	0	0	0	0			154		
D.5a-totaal gemiddeld	**2.30**	**334**	**658**	**294**	**182**	**512**			**308**	**494**	**479**
D5b-1	3			943	555	867	282	221			
D5b-2	2			190	251	211	238	175			
D5b-3	1			0	223	223	431	100			
D5b-4	2			154	176	166	237	411			
D.5b-totaal gemiddeld	**2.00**			**778**	**383**	**668**	**277**	**308**		**509**	**461**
Dx-1	2		0	89	215	195			201		
Dx-2	2		42	0	57	52			198		
Dx-3	2		0	0	0	0			215		
D.x-totaal gemiddeld	**2.00**		**42**	**89**	**200**	**178**			**204**	**198**	**198**
Gemiddelde D2, D5a, Dx	**2.58**	**220**	**195**	**139**	**171**	**257**			**244**	**327**	**326**
X1C-1	4		104	194	684	620	236	245			
X1C-2	2		0	88	100	84	0	50			
X1C-3	2		93	191	149	183	225	199			
X1C-4	1		271	168	0	175	570	73			
X1C-5	2		142	370	241	292	669	250			
X1C-totaal gemiddeld	**2.20**		**114**	**230**	**496**	**351**	**321**	**217**		**320**	**283**
X1A-1	1			0	211	211	191	0			
X1A-2	2			182	0	182	353	282			
X1A-3	1			281	356	315	765	375			
X1A-totaal gemiddeld	**1.33**			**236**	**242**	**240**	**574**	**302**		**346**	**365**
Gemiddelde X1/C & X1/A				**184**	**217**	**258**	**376**	**184**		**333**	**324**

DATASHEET CO2-OVERSCHRIJDING

Gemiddelde CO2-overschrijdingsdoses per dag gedurende stookseizoen in ppmh >1200 ppm

(Overschrijdingsdoses wordt bepaald door vermenigvuldiging van aantal overschrijdingsuren met de hoogte van de overschrijding

Woning/ventilatiesysteem	aantal inw.	gemiddelde overschrijdingsdoses >1200 ppm per dag [ppmh/dag]									
		slaapvertrekken				woonsecties				totale woning	
		zolder	slpkmr 3	slpkmr 2	slpkmr 1	totaal slaap	keuken	wnkmr	woonkeuken	totale woning	gem. pp
A-1	1			126	6	132	204	91		427	427
A-2	2		4	0	19	23	1373	1461		2857	1429
A-3	4		4951	7959	1451	14361	2144	2302		18807	4702
A-4	3		39	5225	365	5629	2947	2830		11406	3802
A-5	2			6	26	32	38	47		117	59
A-totaal gemiddeld	**2.4**		**1665**	**2663**	**373**	**4035**	**1341**	**1346**		**6723**	**2084**
C1-1	1			0	92	92	0	1		93	93
C1-2	2			241	384	625	1389	1419		3433	1717
C1-3	3			6	272	278	13	4		295	98
C1-4	4		5991	163	7416	13570	124	104		13798	3450
C1-5	3		231	1129	13	1373	2254	2533		6160	2053
C1-6	4		149	6802	2119	9070	382	369		9821	2455
C1-totaal gemiddeld	**2.83**		**2124**	**1390**	**1716**	**4168**	**694**	**738**		**5600**	**1644**
C2c-1	1		0	0	235	235			172	407	407
C2c-2	3		381	331	1208	1920			379	2299	766
C2c-3	4		640	192	1179	2011			649	2660	665
C2c-4	3		1195	1202	229	2626			212	2838	946
C2c-5	5	6	2543	276	186	3011			1651	4662	932
C2c-6	4	1315	6783	1565	1460	11123			1616	12739	3185
C.2c-totaal gemiddeld	**3.33**	**660**	**1924**	**594**	**750**	**3488**			**780**	**4267**	**1150**
C4a-1	2		167	1	1	169	68	53		290	145
C4a-2	2		0	98	1	99	361	327		787	394
C4a-3	2			55	0	55	0	1042		1097	549
C4a-4	5		96	11017	8170	19283	824	0		20107	4021
C.4a-totaal gemiddeld	**2.75**		**88**	**2793**	**2043**	**4902**	**313**	**356**		**5570**	**1277**
Gemiddelde C1, C2c, C4a			**1398**	**1358**	**1351**	**3855**	**492**	**532**	**668**	**4793**	**1287**
C4c-1	1		17	0	6	23			39	62	62
C4c-2	1			53	6	59			140	199	199
C4c-3	2		1	124	42	167			1330	1497	749
C4c-4	2			24	4	28			326	354	177
C4c-5	1			2	30	32			30	62	62
C4c-6a	2		0	13	0	13			285	298	149
C4c-6b	3		42	1593	1239	2874			66	2940	980
C.4c-totaal gemiddeld	**1.71**		**15**	**258**	**190**	**457**			**317**	**773**	**340**
D2-1	2		389	2	7	398			85	483	242
D2-2	5		3	53	271	327			242	569	114
D2-3	2		458	25	105	588			57	645	323
D2-4	4		490	18	34	542			694	1236	309
D2-5	4		1	578	195	774			717	1491	373
D2-6	3		1	289	1153	1443			275	1718	573
D.2-totaal gemiddeld	**3.33**		**224**	**161**	**294**	**679**			**345**	**1024**	**322**
D5a-1	1		0	0	3	3			6	9	9
D5a-2	2		1	51	0	52			34	86	43
D5a-3	2		14	512	1	527			13	540	270
D5a-4	3		0	964	58	1022			2	1024	341
D5a-5	2		2836	0	5	2841			93	2934	1467
D5a-6	3		6303	38	98	6439			45	6484	2161
D5a-7	2	32	4	0	0	36			3	39	20
D5a-8	3	161	0	3	1	165			35	200	67
D5a-9	3	308	419	526	0	1253			492	1745	582
D5a-10	2	0	0	0	0	0			20	20	10
D.5a-totaal gemiddeld	**2.30**	**125**	**958**	**209**	**17**	**1234**			**74**	**1308**	**497**
D5b-1	3			5328	761	6089	155	482		6726	2242
D5b-2	2			203	143	346	200	117		663	332
D5b-3	1			0	78	78	125	2		205	205
D5b-4	2			74	90	164	83	1115		1362	681
D.5b-totaal gemiddeld	**2.00**			**1401**	**268**	**1669**	**141**	**429**		**2239**	**865**
Dx-1	2		0	33	438	471			598	1069	535
Dx-2	2		5	0	12	17			561	578	289
Dx-3	2		0	0	0	0			506	506	253
D.x-totaal gemiddeld	**2.00**		**2**	**11**	**150**	**163**			**555**	**718**	**359**
Gemiddelde D2, D5a, Dx	**2.58**	**125**	**575**	**163**	**125**	**889**			**236**	**1125**	**420**
X1C-1	4		71	31	4513	4615	267	866		5748	1437
X1C-2	2		0	36	1	37	0	1		38	19
X1C-3	2		27	1333	107	1467	366	685		2518	1259
X1C-4	1		19	123	0	142	57	16		215	215
X1C-5	2		17	1018	924	1959	448	5		2412	1206
X1C-totaal gemiddeld	**2.20**		**27**	**508**	**1109**	**1644**	**228**	**315**		**2186**	**827**
X1A-1	1			0	299	299	44	0		343	343
X1A-2	2			69	0	69	212	852		1133	567
X1A-3	1			132	139	271	880	300		1451	1451
X1A-totaal gemiddeld	**1.33**			**67**	**146**	**213**	**379**	**384**		**976**	**787**
Gemiddelde X1/C & X1/A	**1.88**		**27**	**343**	**748**	**1107**	**284**	**341**		**1732**	**812**

DATASHEET CO2-OVERSCHRIJDING

Gemiddelde CO2-overschrijdingsdoses per stookseizoen in kppmh >1200 ppm

Woning/ventilatiesysteem	aantal inw.	overschrijdingsdosis per stookseizoen >1200 ppm in [kppmh/st.szn]									
		slaapvertrekken				woonsecties				totale woning	
		zolder	slpkmr 3	slpkmr 2	slpkmr 1	totaal slaap	keuken	wnkmr	woonkeuken	totale woning	gem. pp
A-1	1			27	1	28	43	19		91	91
A-2	2		1	0	4	5	291	310		606	303
A-3	4		1050	1687	308	3045	455	488		3987	997
A-4	3		8	1108	77	1193	625	600		2418	806
A-5	2			1	6	7	8	10		25	12
A-totaal gemiddeld	**2.4**		**353**	**565**	**79**	**856**	**284**	**285**		**1425**	**442**
C1-1	1			0	20	20	0	0		20	20
C1-2	2			51	81	133	294	301		728	364
C1-3	3			1	58	59	3	1		63	21
C1-4	4		1270	35	1572	2877	26	22		2925	731
C1-5	3		49	239	3	291	478	537		1306	435
C1-6	4		32	1442	449	1923	81	78		2082	521
C1-totaal gemiddeld	**2.83**		**450**	**295**	**364**	**884**	**147**	**157**		**1187**	**349**
C2c-1	1		0	0	50	50			36	86	86
C2c-2	3		81	70	256	407			80	487	162
C2c-3	4		136	41	250	426			138	564	141
C2c-4	3		253	255	49	557			45	602	201
C2c-5	5	1	539	59	39	638			350	988	198
C2c-6	4	279	1438	332	310	2358			343	2701	675
C.2c-totaal gemiddeld	**3.33**	**140**	**408**	**126**	**159**	**739**			**165**	**905**	**244**
C4a-1	2		35	0	0	36	14	11		61	31
C4a-2	2		0	21	0	21	77	69		167	83
C4a-3	2			12	0	12	0	221		233	116
C4a-4	5		20	2336	1732	4088	175	0		4263	853
C.4a-totaal gemiddeld	**2.75**		**19**	**592**	**433**	**1039**	**66**	**75**		**1181**	**271**
Gemiddelde C1,C2c, C4a	**3.00**	**140**	**321**	**306**	**304**		**115**	**124**	**165**	**1080**	**290**
C4c-1	1		4	0	1	5			8	13	13
C4c-2	1			11	1	13			30	42	42
C4c-3	2		0	26	9	35			282	317	159
C4c-4	2			5	1	6			69	75	38
C4c-5	1			0	6	7			6	13	13
C4c-6a	2		0	3	0	3			60	63	32
C4c-6b	3		9	338	263	609			14	623	208
C.4c-totaal gemiddeld	**1.71**		**3**	**55**	**40**	**97**			**67**	**164**	**72**
D2-1	2		82	0	1	84			18	102	51
D2-2	5		1	11	57	69			51	121	24
D2-3	2		97	5	22	125			12	137	68
D2-4	4		104	4	7	115			147	262	66
D2-5	4		0	123	41	164			152	316	79
D2-6	3		0	61	244	306			58	364	121
D.2-totaal gemiddeld	**3.33**		**47**	**34**	**62**	**144**			**73**	**217**	**68**
D5a-1	1		0	0	1	1			1	2	2
D5a-2	2		0	11	0	11			7	18	9
D5a-3	2		3	109	0	112			3	114	57
D5a-4	3		0	204	12	217			0	217	72
D5a-5	2		601	0	1	602			20	622	311
D5a-6	3		1336	8	21	1365			10	1375	458
D5a-7	2	7	1	0	0	8			1	8	4
D5a-8	3	34	0	1	0	35			7	42	14
D5a-9	3	65	89	112	0	266			104	370	123
D5a-10	2	0	0	0	0	0			4	4	2
D.5a-totaal gemiddeld	**2.30**	**27**	**203**	**44**	**4**	**262**			**16**	**277**	**105**
D5b-1	3			1130	161	1291	33	102		1426	475
D5b-2	2			43	30	73	42	25		141	70
D5b-3	1			0	17	17	27	0		43	43
D5b-4	2			16	19	35	18	236		289	144
D.5b-totaal gemiddeld	**2.00**			**297**	**57**	**354**	**30**	**91**		**475**	**183**
Dx-1	2		0	7	93	100			127	227	113
Dx-2	2		1	0	3	4			119	123	61
Dx-3	2		0	0	0	0			107	107	54
D.x-totaal gemiddeld	**2.00**		**0**	**2**	**32**	**34**			**118**	**152**	**76**
Gemiddelde D2, D5a, Dx	**2.58**	**27**	**122**	**35**	**27**	**189**			**50**	**239**	**89**
X1C-1	4		15	7	957	978	57	184		1219	305
X1C-2	2		0	8	0	8	0	0		8	4
X1C-3	2		6	283	23	311	78	145		534	267
X1C-4	1		4	26	0	30	12	3		46	46
X1C-5	2		4	216	196	415	95	1		511	256
X1C-totaal gemiddeld	**2.20**		**6**	**108**	**235**	**349**	**48**	**67**		**463**	**175**
X1A-1	1			0	63	63	9	0		73	73
X1A-2	2			15	0	15	45	181		240	120
X1A-3	1			28	29	57	187	64		308	308
X1A-totaal gemiddeld	**1.33**			**14**	**31**	**45**	**80**	**81**		**207**	**167**
Gemiddelde X1/C & X1/A	**1.88**		**6**	**73**	**159**	**235**	**60**	**72**		**367**	**172**

DATASHEET RELATIVE HUMIDITY (RH)

Average number of hours per day outside comfortzone 30 - 70% RH

		RH > 70% [in hours per day during heasting season]					**RH < 30%** [in hours per day during heasting season]				
Ventilation System Type		Cumulative Whole dwelling	Living section (& i.a. comb kitchen)	Sleeping section	Kitchen	Bathroom	Cumulative Whole dwelling	Living section	Sleeping section	Kitchen	Bathroom & i.a. utility room
	Anonym. address	h/day	h/day	h/day	h/day	h/day	h/day	h/day	h/day	h/day	h/day
A	**TOTAL AVERAGES**	1.47	0.00	0.00	0.00	1.46	27.26	4.40	12.40	5.44	5.02
	STANDARD DEVIATION	*1.45*	*0.00*	*0.01*	*0.00*	*1.45*	*5.69*	*1.67*	*5.98*	*5.37*	*6.18*
	A-1	3.67	0.00	0.00	0.00	3.67	28.00	6.00	14.00	7.00	1.00
	A-2	0.47	0.00	0.02	0.00	0.45	27.00	4.00	5.00	4.00	14.00
	A-3	0.81	0.01	0.00	0.00	0.80	34.00	2.00	9.00	14.00	9.00
	A-4	2.18	0.00	0.00	0.00	2.18	29.00	6.00	21.00	1.00	1.00
	A-5	0.21	0.00	0.00	0.00	0.21	18.30	4.00	13.00	1.20	0.10
C1	**TOTAL AVERAGES**	1.31	0.00	0.00	0.00	1.31	49.53	6.83	24.83	7.77	10.10
	STANDARD DEVIATION	*1.91*	*0.00*	*0.00*	*0.00*	*1.91*	*40.73*	*9.83*	*25.97*	*9.91*	*10.72*
	C1-1	0.00	0.00	0.00	0.00	0.00	66.00	0.00	66.00	0.00	0.00
	C1-2	0.25	0.00	0.00	0.00	0.25	74.20	15.00	30.00	14.60	14.60
	C1-3	0.21	0.00	0.00	0.00	0.21	110.00	23.00	42.00	24.00	21.00
	C1-4	1.98	0.00	0.00	0.00	1.98	14.00	3.00	1.00	8.00	2.00
	C1-5	4.93	0.00	0.00	0.00	4.93	4.00	0.00	4.00	0.00	0.00
	C1-6	0.50	0.00	0.00	0.00	0.50	29.00	0.00	6.00	0.00	23.00
C.2c	**TOTAL AVERAGES**	1.09	0.00	0.49		0.60	20.03	2.17	7.50		10.37
	STANDARD DEVIATION	*1.21*	*0.00*	*1.20*		*0.57*	*12.75*	*2.86*	*7.66*		*6.21*
	C2c-1	0.42	0.00	0.00		0.42	20.50	0.00	7.00		13.50
	C2c-2	0.72	0.00	0.00		0.72	18.00	4.00	8.00		6.00
	C2c-3	0.06	0.00	0.00		0.06	25.00	2.00	3.00		20.00
	C2c-4	0.38	0.00	0.00		0.38	7.00	0.00	0.00		7.00
	C2c-5	3.27	0.00	2.94		0.33	41.70	7.00	22.00		12.70
	C2c-6	1.68	0.00	0.00		1.68	8.00	0.00	5.00		3.00
C.4a	**TOTAL AVERAGES**	0.29	0.00	0.00	0.00	0.29	29.70	4.50	12.00	2.73	10.48
	STANDARD DEVIATION	*0.49*	*0.00*	*0.00*	*0.00*	*0.49*	*20.05*	*3.11*	*8.04*	*2.74*	*7.83*
	C4a-1	1.02	0.00	0.00	0.00	1.02	43.00	6.00	15.00	6.00	16.00
	C4a-2	0.00	0.00	0.00	0.00	0.00	45.80	5.00	20.00	3.90	16.90
	C4a-3	0.15	0.00	0.00	0.00	0.15	28.00	7.00	12.00	0.00	9.00
	C4a-5	0.00	0.00	0.00	0.00	0.00	2.00	0.00	1.00	1.00	0.00
TOTAL AVERAGE C1, C2c, C4a		0.97	0.00	0.18	0.00	0.79	33.51	4.50	15.13	5.75	10.29
OVERALL STANDARD DEVIATION		*1.39*	*0.00*	*0.73*	*0.00*	*1.25*	*29.44*	*6.42*	*17.91*	*7.99*	*7.97*
C.4c	**TOTAL AVERAGES**	1.32	0.00	0.00		1.32	17.13	5.17	9.17		2.80
	STANDARD DEVIATION	*1.70*	*0.00*	*0.00*		*1.70*	*14.92*	*3.66*	*9.60*		*4.11*
	C4c-1	0.06	0.00	0.00		0.06	8.00	2.00	5.00		1.00
	C4c-2	0.00	0.00	0.00		0.00	7.50	7.00	0.00		0.50
	C4c-3	1.64	0.00	0.00		1.64	37.00	11.00	24.00		2.00
	C4c-4	1.57	0.00	0.00		1.57	12.30	4.00	6.00		2.30
	C4c-5	0.22	0.00	0.00		0.22	35.00	6.00	18.00		11.00
	C4c-6a	4.44	0.00	0.00		4.44	3.00	1.00	2.00		0.00
	C4c-6b										
D2	**TOTAL AVERAGES**	1.52	0.00	0.64		0.88	23.02	0.00	17.83		5.18
	STANDARD DEVIATION	*1.38*	*0.00*	*1.56*		*0.76*	*10.69*	*0.00*	*5.88*		*5.91*
	D2-1	0.66	0.00	0.00		0.66	21.00	0.00	19.00		2.00
	D2-2	1.60	0.00	0.00		1.60	15.30	0.00	11.00		4.30
	D2-3	0.35	0.00	0.00		0.35	26.00	0.00	23.00		3.00
	D2-4	0.47	0.00	0.00		0.47	18.80	0.00	15.00		3.80
	D2-5	2.05	0.00	0.00		2.05	14.00	0.00	13.00		1.00
	D2-6	3.97	0.00	3.81		0.16	43.00	0.00	26.00		17.00
D5a	**TOTAL AVERAGES**	0.54	0.00	0.00		0.54	47.69	5.20	32.40		10.09
	STANDARD DEVIATION	*0.79*	*0.00*	*0.00*		*0.79*	*20.43*	*5.65*	*20.79*		*8.69*
	D5a-1	0.14	0.00	0.00		0.14	44.00	11.00	22.00		11.00
	D5a-2	0.18	0.00	0.00		0.18	12.00	6.00	6.00		0.00
	D5a-3	2.61	0.00	0.00		2.61	66.00	16.00	27.00		23.00
	D5a-4	0.47	0.00	0.00		0.47	52.50	3.00	29.00		20.50
	D5a-5	0.05	0.00	0.00		0.05	45.80	6.00	27.00		12.80
	D5a-6	0.19	0.00	0.00		0.19	47.00	10.00	17.00		20.00
	D5a-7	1.05	0.00	0.00		1.05	46.00	0.00	44.00		2.00
	D5a-8	0.32	0.00	0.00		0.32	31.40	0.00	29.70		1.70
	D5a-9	0.35	0.00	0.00		0.35	42.00	0.00	39.00		3.00
	D5a-10	0.03	0.00	0.00		0.03	90.20	0.00	83.30		6.90
D5b	**TOTAL AVERAGES**	0.35	0.00	0.00	0.00	0.35	33.15	5.25	11.00	9.23	7.68
	STANDARD DEVIATION	*0.20*	*0.00*	*0.00*	*0.00*	*0.20*	*11.47*	*3.77*	*3.65*	*7.93*	*4.46*
	D5b-1	0.48	0.00	0.00	0.00	0.48	24.00	5.00	7.00	5.00	7.00
	D5b-2	0.34	0.00	0.00	0.00	0.34	24.40	0.00	15.00	5.80	3.60
	D5b-3	0.08	0.00	0.00	0.00	0.08	36.00	8.00	9.00	5.00	14.00
	D5b-4	0.50	0.00	0.00	0.00	0.50	48.20	8.00	13.00	21.10	6.10
Dx	**TOTAL AVERAGES**	2.78	0.00	0.00		2.78	18.33	3.00	10.00		5.33
	STANDARD DEVIATION	*1.70*	*0.00*	*0.00*		*1.70*	*5.13*	*1.73*	*5.57*		*1.53*
	Dx-1	2.07	0.00	0.00		2.07	14.00	4.00	5.00		5.00
	Dx-2	4.72	0.00	0.00		4.72	17.00	1.00	9.00		7.00
	Dx-3	1.56	0.00	0.00		1.56	24.00	4.00	16.00		4.00
TOTAL AVERAGES D2, D5a, Dx		1.20	0.00	0.20		1.00	35.26	3.21	24.26		7.79
OVERALL STANDARD DEVIATION		1.36	0.00	0.87		1.20	20.66	4.69	17.71		7.34
X1/C	**TOTAL AVERAGES**	1.53	0.00	0.00	0.01	1.52	25.80	4.80	12.80	5.00	3.20
	STANDARD DEVIATION	*1.55*	*0.00*	*0.00*	*0.03*	*1.54*	*8.11*	*3.11*	*4.92*	*2.83*	*1.79*
	X1C-1	2.23	0.00	0.00	0.07	2.16	21.00	7.00	11.00	0.00	3.00
	X1C-2	0.70	0.00	0.00	0.00	0.70	24.00	0.00	15.00	6.00	3.00
	X1C-3	0.70	0.00	0.00	0.00	0.70	29.00	4.00	16.00	6.00	3.00
	X1C-4	3.92	0.00	0.00	0.00	3.92	17.00	5.00	5.00	6.00	1.00
	X1C-5	0.12	0.00	0.00	0.00	0.12	38.00	8.00	17.00	7.00	6.00
X1/A	**TOTAL AVERAGES**	7.35	0.00	0.00	0.00	7.35	26.60	5.50	12.50	2.70	5.90
	STANDARD DEVIATION	*10.39*	*0.00*	*0.00*	*0.00*	*10.39*	*29.98*	*7.78*	*17.68*	*3.82*	*8.34*
	X1A-#										
	X1A-1	14.70	0.00	0.00	0.00	14.70	5.40	0.00	0.00	5.40	0.00
	X1A-2										
	X1A-3	0.00	0.00	0.00	0.00	0.00	47.80	11.00	25.00	0.00	11.80
TOTAL AVERAGES X1/C, X1/A		3.19	0.00	0.00	0.01	3.18	26.03	5.00	12.71	4.34	3.97
OVERALL STANDARD DEVIATION		5.26	0.00	0.00	0.02	5.26	13.92	4.08	8.26	3.00	3.93

DATASHEET MECHANICAL VENTILATION RATES

Heating season average mechanical hourly ventilation rates and power consumption

		Measured Mechanical Ventilation Rates														
		Centr. MEV-unit		Centr. WTW-unit						Total of Local HR-units		Total mech vent. rate (kitchen hood excluded)				
						Local HR Living		Local HR bedrooms								
Ventilation System Type		heating season average ventilation rate	average power consumption	heating season average ventilation rate	average power cons.	heating season average ventilation rate	average power cons.	heating season average ventilation rate	average power cons.	heating season average ventilation rate	average power cons.	heating season average ventilation rate	average power cons.	average ventilation rate per m2 heated area		average ventilation rate per person
	Anonym. address	[m3/h]	[W]	[m3/h]	[W]	[m3/h]	[W]	[m3/h]	[W]	[m3/h]	[W]	[m3/h]	[W]	l/s/m2	m3/h/m2	m3/h/pp
A	**TOTAL AVERAGES**															
	STANDARD DEVIATION															
	A-1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
C1	**TOTAL AVERAGES**											51.7	22.3	0.11	0.41	12.93
	STANDARD DEVIATION															
	C1-1	no data	no data	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	no data	no data	no data	no data	no data
	C1-2	no data	no data	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	no data	no data	no data	no data	no data
	C1-3	no data	no data	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	no data	no data	no data	no data	no data
	C1-4	no data	no data	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	no data	no data	no data	no data	no data
	C1-5	no data	no data	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	no data	no data	no data	no data	no data
	C1-6	51.7	22.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	51.7	22.3	0.11	0.41	12.93
C.2c	**TOTAL AVERAGES**	104.6	21.1									104.6	21.1	0.30	1.09	41.9
	STANDARD DEVIATION	13.8	2.5									13.8	2.5	0.04	0.14	32.8
	C2c-1	107.0	20.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	107.0	20.2	0.309	1.11	107.00
	C2c-2	100.2	19.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	100.2	19.5	0.290	1.04	33.40
	C2c-3	112.4	26.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	112.4	26.3	0.325	1.17	28.10
	C2c-4	118.0	20.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	118.0	20.5	0.341	1.23	39.33
	C2c-5	79.2	20.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	79.2	20.2	0.229	0.82	15.84
	C2c-6	111.0	20.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	111.0	20.1	0.321	1.15	27.75
C.4a	**TOTAL AVERAGES**											95.1	5.7	0.40	1.44	41.1
	STANDARD DEVIATION											15.5	0.5	0.07	0.24	17.5
	C4a-1	79.0	5.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	79.0	5.3	0.332	1.20	39.50
	C4a-2	101.9	6.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	101.9	6.2	0.428	1.54	50.95
	C4a-3	113.5	6.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	113.5	6.0	0.477	1.72	56.75
	C4a-5	86.1	5.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	86.1	5.1	0.362	1.30	17.22
TOTAL AVERAGE C1, C2c, C4a		96.4	15.6									96.4	15.6	0.32	1.15	39.0
OVERALL STANDARD DEVIATION		20.2	8.1									20.2	8.1	0.1	0.3	26.6
C.4c	**TOTAL AVERAGES**	76.4	21.3									76.4	21.3	0.20	0.71	48.7
	STANDARD DEVIATION	21.2	9.2									21.2	9.2	0.05	0.20	13.9
	C4c-1	57.0	12.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	57.0	12.2	0.146	0.53	57.00
	C4c-2	72.2	22.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	72.2	22.0	0.185	0.67	72.20
	C4c-3	88.6	20.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	88.6	20.7	0.227	0.82	44.30
	C4c-4	79.4	25.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	79.4	25.7	0.204	0.73	39.70
	C4c-5	56.9	13.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	56.9	13.9	0.146	0.53	56.90
	C4c-6	64.0	15.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	64.0	15.7	0.164	0.59	32.00
	C4c-6	116.6	39.2									116.6	39.2	0.299	1.08	38.87
D2	**TOTAL AVERAGES**	128.3	17.0	166.4	40.0							160.0	36.2	0.38	1.38	51.8
	STANDARD DEVIATION			29.7	21.6							30.8	21.5	0.10	0.35	15.1
	D2-1	n.a.	n.a.	154.6	36.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	154.6	36.0	0.307	1.11	77.30
	D2-2	n.a.	n.a.	200.8	52.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	200.8	52.2	0.505	1.82	40.16
	D2-3	n.a.	n.a.	125.7	19.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	125.7	19.2	0.257	0.93	62.85
	D2-4	n.a.	n.a.	189.5	70.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	189.5	70.8	0.361	1.30	47.38
	D2-5	n.a.	n.a.	161.3	22.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	161.3	22.0	0.488	1.76	40.33
	D2-6	128.3	17.0			n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	128.3	17.0	0.388	1.40	42.77
D5a	**TOTAL AVERAGES**			96.7	18.9							96.7	18.9	0.25	0.89	51.9
	STANDARD DEVIATION			12.0	0.5							12.0	0.5	0.03	0.11	27.4
	D5a-1	n.a.	n.a.	92.2	19.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	92.2	19.2	0.276	0.99	92.20
	D5a-2	n.a.	n.a.	83.0	18.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	83.0	18.0	0.192	0.69	41.50
	D5a-3	n.a.	n.a.	89.1	19.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	89.1	19.2	0.266	0.96	44.55
	D5a-4	n.a.	n.a.	89.5	19.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	89.5	19.2	0.268	0.96	29.83
	D5a-5	n.a.	n.a.	89.2	18.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	89.2	18.8	0.267	0.96	44.60
	D5a-6	n.a.	n.a.	84.0	18.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	84.0	18.2	0.195	0.70	28.00
	D5a-7	n.a.	n.a.	109.7	18.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	109.7	18.8	0.249	0.90	54.85
	D5a-8	n.a.	n.a.	115.1	19.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	115.1	19.0	0.262	0.94	38.37
	D5a-9	n.a.	n.a.	105.5	19.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	105.5	19.4	0.240	0.86	35.17
	D5a-10	n.a.	n.a.	110.0	19.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	110.0	19.1	0.250	0.90	110.00
D5b	**TOTAL AVERAGES**	64.7	6.3			6.2	1.6	6.7	2.6	10.8	3.7	72.7	9.1	0.31	1.10	39.5
	STANDARD DEVIATION	23.6	0.5			0.1	0.0	4.3	1.7	5.6	2.0	19.7	2.2	0.08	0.30	12.8
	D5b-1	80.4	6.7	n.a.	n.a.	0	0.0	9.8	3.6	9.8	3.6	90.2	10.3	0.379	1.37	30.07
	D5b-2	43.2	6.0	n.a.	n.a.	6.1	1.6	7	3.1	13.1	4.7	56.3	10.7	0.237	0.85	28.15
	D5b-3	45.7	6.9	n.a.	n.a.	6.2	1.6	3.2	1.2	9.4	2.8	55.1	9.7	0.232	0.83	55.10
	D5b-4	89.3	5.8	n.a.	n.a.	0	0.0	0	0.0	0.0	0.0	89.3	5.8	0.375	1.35	44.65
Dx	**TOTAL AVERAGES**			71.7	22.4							71.7	22.4	0.18	0.66	35.8
	STANDARD DEVIATION			16.1	4.7							16.1	4.7	0.04	0.15	8.1
	Dx-1	n.a.	n.a.	61.0	17.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	61.0	17.2	0.156	0.56	30.50
	Dx-2	n.a.	n.a.	90.2	26.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	90.2	26.2	0.231	0.83	45.10
	Dx-3	n.a.	n.a.	63.8	23.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	63.8	23.8	0.164	0.59	31.90
TOTAL AVERAGES D2, D5a, Dx												112.76	24.92	0.28	1.01	49.33
OVERALL STANDARD DEVIATION												39.16	13.95	0.10	0.34	21.94
X1/C	**TOTAL AVERAGES**	59.6	4.5			9.2	2.1			9.2	2.1	68.8	6.7	0.29	1.04	37.3
	STANDARD DEVIATION	19.7	0.4			2.9	0.5			2.9	0.5	19.3	0.5	0.08	0.29	18.8
	X1C-1	56.0	4.3	n.a.	n.a.	11.4	2.6	n.a.	n.a.	11.4	2.6	67.4	6.9	0.283	1.02	16.85
	X1C-2	37.5	4.7	n.a.	n.a.	7.3	1.7	n.a.	n.a.	7.3	1.7	44.8	6.4	0.188	0.68	22.40
	X1C-3	57.8	4.3	n.a.	n.a.	13.2	2.8	n.a.	n.a.	13.2	2.8	71.0	7.1	0.299	1.07	35.50
	X1C-4	55.0	4.2	n.a.	n.a.	7.4	1.7	n.a.	n.a.	7.4	1.7	62.4	5.9	0.262	0.94	62.40
	X1C-5	91.7	5.2	n.a.	n.a.	6.6	1.7	n.a.	n.a.	6.6	1.7	98.3	6.9	0.413	1.49	49.15
X1/A	**TOTAL AVERAGES**					7.10	1.95			7.10	1.95					
	STANDARD DEVIATION					4.51	0.62			4.51	0.62					
	X1A-#	n.a.	n.a.	n.a.	n.a.	5.5	1.8	n.a.	n.a.	5.5	1.8	n.a.	n.a.	n.a.	n.a.	n.a.
	X1A-1	n.a.	n.a.	n.a.	n.a.	11.9	2.7	n.a.	n.a.	11.9	2.7	n.a.	n.a.	n.a.	n.a.	n.a.
	X1A-2	n.a.	n.a.	n.a.	n.a.	9.4	2.1	n.a.	n.a.	9.4	2.1	n.a.	n.a.	n.a.	n.a.	n.a.
	X1A-3	n.a.	n.a.	n.a.	n.a.	1.6	1.2	n.a.	n.a.	1.6	1.2	n.a.	n.a.	n.a.	n.a.	n.a.
TOTAL AVERAGES X1/C, X1/A																
OVERALL STANDARD DEVIATION																

DATASHEET ENERGY CONSUMPTION

Ventilation System Type		Thermal energy content of the mechanically echanged air per average heating season	Propotion of mechanically induced air that passes HR-unit	Average η_{HR} @achieved flow rates according to. EN131241 -7/8	Thermal energy losses due to mechanical ventilation with η_{HR} acc. to. EN131241 -7/8	Thermal energy losses due to mechanical ventilation with default real-life η_{HR} = 80%	Thermal energy losses due to mechanical ventilation with default real-life η_{HR} = 80% AND $\eta_{heating.syst}$ = 85%	Power consumption for mechanical ventilation units (electricity converted to primary) per heating season	Total primary energy use for mechanical ventilation per av. heating season per dwelling	Total primary energy use for mechanical ventilation per av. heating season per m2 of heated surface
	Anonym. address	MJ/h.s.	%	%	MJ/h.s.	MJ/h.s.	MJ/h.s.	MJ/h.s.	MJ/h.s.	MJ/m2/h.s.
A	**TOTAL AVERAGES**									
	STANDARD DEVIATION									
	A-1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A-5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
C1	**TOTAL AVERAGES**				4496	4496	5289	1019	6308	50
	STANDARD DEVIATION									
	C1-1	no data	0.00%	n.a.						
	C1-2	no data	0.00%	n.a.						
	C1-3	no data	0.00%	n.a.						
	C1-4	no data	0.00%	n.a.						
	C1-5	no data	0.00%	n.a.						
	C1-6	4496	0.00%	n.a.	4496	4496	5289	1019	6308	50.22
C.2c	**TOTAL AVERAGES**	8920	0		8920	8920	10494	968	11463	119
	STANDARD DEVIATION	1077	0		1077	1077	1267	116	1262	13
	C2c-1	8025	0.00%	n.a.	8025	8025	9441	925	10366	107.85
	C2c-2	8595	0.00%	n.a.	8595	8595	10112	894	11006	114.50
	C2c-3	8665	0.00%	n.a.	8665	8665	10194	1203	11398	118.58
	C2c-4	10075	0.00%	n.a.	10075	10075	11853	940	12793	133.09
	C2c-5	7769	0.00%	n.a.	7769	7769	9140	926	10066	104.73
	C2c-6	10392	0.00%	n.a.	10392	10392	12226	920	13146	136.77
C.4a	**TOTAL AVERAGES**	7845	0		7845	7845	9229	259	9488	144
	STANDARD DEVIATION	1371	0		1371	1371	1613	25	1628	25
	C4a-1	6060	0.00%	n.a.	6060	6060	7129	243	7372	111.58
	C4a-2	8063	0.00%	n.a.	8063	8063	9486	284	9770	147.87
	C4a-3	9396	0.00%	n.a.	9396	9396	11054	276	11330	171.48
	C4a-5	7859	0.00%	n.a.	7859	7859	9246	234	9479	143.48
TOTAL AVERAGE C1, C2c, C4a		8127	0		8127	8127	9561	715	10276	122
OVERALL STANDARD DEVIATION		1695	0		1695	1695	1994	371	2064	31
C.4c	**TOTAL AVERAGES**	6693	0		6693	6693	7874	977	8851	82
	STANDARD DEVIATION	2522	0		2522	2522	2968	422	3377	31
	C4c-1	4590	0.00%	n.a.	4590	4590	5400	559	5959	55.00
	C4c-2	6383	0.00%	n.a.	6383	6383	7509	1007	8517	78.62
	C4c-3	6807	0.00%	n.a.	6807	6807	8008	948	8956	82.67
	C4c-4	6836	0.00%	n.a.	6836	6836	8042	1177	9219	85.10
	C4c-5	4309	0.00%	n.a.	4309	4309	5069	637	5706	52.67
	C4c-6a	5991	0.00%	n.a.	5991	5991	7048	719	7767	71.70
	C4c-6b	11932	0.00%	n.a.	11932	11932	14038	1795	15833	146.15
D2	**TOTAL AVERAGES**	12964	100.00%	93.25%	914	2656	3124	1834	4958	40
	STANDARD DEVIATION	3219	0.00%	*0.83%*	319	699	822	991	1787	14
	D2-1	11494	100.00%	93.44%	754	2299	2704	1649	4353	31.12
	D2-2	15694	100.00%	92.08%	1243	3139	3693	2392	6085	55.05
	D2-3	9123	100.00%	94.40%	511	1825	2147	879	3026	22.31
	D2-4	17899	100.00%	93.10%	1235	3580	4211	3242	7453	51.05
	D2-5	12180	100.00%	93.21%	827	2436	2866	1006	3872	42.13
	D2-6	11395	0.00%	0.00%	11395	11395	13406	778	14184	154.35
D5a	**TOTAL AVERAGES**	7774	1	87.89%	933	1555	1829	866	2695	25
	STANDARD DEVIATION	*1252*	*0*	*1.44%*	*130*	*250*	*295*	*21*	*303*	*4*
	D5a-1	6735	100.00%	86.70%	896	1347	1585	880	2465	26.53
	D5a-2	7078	100.00%	86.96%	923	1416	1665	824	2490	20.77
	D5a-3	8752	100.00%	86.62%	1171	1750	2059	881	2940	31.64
	D5a-4	7368	100.00%	86.74%	977	1474	1734	881	2615	28.14
	D5a-5	7157	100.00%	86.74%	949	1431	1684	860	2543	27.37
	D5a-6	6259	100.00%	86.93%	818	1252	1473	835	2308	19.26
	D5a-7	9253	100.00%	89.56%	966	1851	2177	861	3038	24.85
	D5a-8	9611	100.00%	89.20%	1038	1922	2261	871	3133	25.62
	D5a-9	9026	100.00%	89.84%	917	1805	2124	888	3012	24.64
	D5a-10	6503	100.00%	89.59%	677	1301	1530	875	2405	19.67
D5b	**TOTAL AVERAGES**	5931	17.06%	89.00%	5361	5419	6375	417	6792	103
	STANDARD DEVIATION	1909	6.20%	*0.00%*	2140	2115	2488	103	2426	37
	D5b-1	7755	10.86%	89.00%	7005	7081	8330	469	8800	133.19
	D5b-2	4135	23.27%	89.00%	3279	3366	3960	489	4448	67.32
	D5b-3	4437	17.06%	89.00%	3763	3831	4507	444	4951	74.94
	D5b-4	7398	0.00%	89.00%	7398	7398	8704	266	8969	135.75
Dx	**TOTAL AVERAGES**	6319	100.00%	95.30%	307	1264	1487	1026	2513	23
	STANDARD DEVIATION	1712	0.00%	0.86%	142	342	403	213	551	5
	Dx-1	5673	100.00%	95.84%	236	1135	1335	788	2122	19.59
	Dx-2	8260	100.00%	94.31%	470	1652	1944	1200	3143	29.02
	Dx-3	5023	100.00%	95.74%	214	1005	1182	1090	2272	20.97
TOTAL AVERAGES D2, D5a, Dx		9183	100.00%	90.61%	1380	2316	2725	1141	3866	29
OVERALL STANDARD DEVIATION		3350	0.00%	3.41%	2443	2296	2701	639	2847	31
X1/C	**TOTAL AVERAGES**	6249	14.07%	88.73%	5497	5571	6554	305	6858	104
	STANDARD DEVIATION	1579	4.81%	0.39%	1570	1569	1846	21	1856	28
	X1C-1	6417	16.91%	88.60%	5455	5548	6527	316	6843	103.57
	X1C-2	4016	16.29%	88.98%	3434	3493	4109	295	4404	66.66
	X1C-3	6856	18.59%	88.10%	5733	5836	6866	325	7191	108.84
	X1C-4	5650	11.86%	88.97%	5054	5114	6017	272	6289	95.18
	X1C-5	8307	6.71%	88.98%	7811	7861	9248	315	9563	144.75
X1/A	**TOTAL AVERAGES**		100.00%	87.51%	105	166	196	89	285	5.08
	STANDARD DEVIATION		0.00%	0.86%	69	106	125	29	149	2.65
	X1A-#	no data	100.00%	86.59%	157	234	275	82	358	6.38
	X1A-1	no data	100.00%	87.56%	168	270	318	124	441	7.86
	X1A-2	no data	100.00%	88.65%	70	123	145	96	241	4.30
	X1A-3	no data	100.00%	87.23%	24	38	44	55	99	1.77
TOTAL AVERAGES X1/C, X1/A										
OVERALL STANDARD DEVIATION										