Possible UK residential demand-controlled ventilation assessment methodology

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ABSTRACT

Demand controlled ventilation (DCV) can improve the energy performance of all kinds of ventilation systems, in residential and non-residential buildings and is already part of the European Lot 6 and Ecodesign regulations and standards. However, the lack of recognition of DCV in SAP (Standard Assessment Procedure) forms a great barrier for the use of this technology in the UK. A methodology was developed to prove the guarantee on good IAQ, with potential saving on heating and auxiliary energy by modulating ventilation rates based on actual demand.

It is generally accepted that a DCV system, with air flow rates lower than UK recommended values, can only be recognised provided that the IAQ is at least as good as the worst performing constant airflow ventilation system in the regulation. Therefore a model, based on UK reference dwellings and systems, was developed and particular attention was paid to dwellings with low air permeabilities.

A representative simulation model was established using the reliable multi-zone simulation tool Contam. Two different dwelling types, a detached house and a flat, were modelled. These dwelling types represent a large part of the UK housing stock.

Hypotheses concerning the dwelling characteristics (detached house and flat), the weather data, the location, the occupancy, the production of contaminants, the user behaviour and the ventilation components were made.

The IAQ achieved with a number of ventilation systems with or without DCV were assessed using (1) relative humidity (RH), (2) (total) volatile organic compounds ((T)VOC) and (3) carbon dioxide (CO2), after which the energy saving of hypothetical DCV systems were determined with respect to the four different reference system types in the regulation.

Each ventilation system was modelled at 5 building air permeabilities: 0.6; 2.5; 5; 7.5 and 10 $(m^3/h)/m^2$ and for the 2 types of dwellings.

It is found that different configurations of DCV systems can comply with the 3 IAQ criteria, creating equally good or even better IAQ than the reference ventilation systems, while reducing energy consumption for heating and fan power consumption (average reduction factors of 0.83 and 0.93 respectively with the examples taken into account).

KEYWORDS

Demand controlled ventilation, simulation, IAQ, Energy savings

1 INTRODUCTION

Demand controlled ventilation (DCV) can improve the energy performance of all kinds of ventilation systems, in residential and non-residential buildings and is already part of the European Lot 6 and Ecodesign regulations and standards. However, the lack recognition of DCV in SAP forms a great barrier for the use of this technology in the UK. The following study will demonstrate the energy-savings potential in UK dwellings.

It is generally accepted that a DCV system can only be recognised provided that the IAQ is at least as good as the worst ventilation systems 1, 2, 3 or 4 according to Approved Document F (ADF). Therefore, the DCV group developed a model based on UK reference dwellings and systems, and particular attention was paid to dwellings with low air permeabilities.

A representative simulation model was established using the reliable multi-zone simulation tool Contam, as proposed by BRE and supported by PHE (I-VII). Similar to the study of Palmer et al. (I), two different dwelling types, a detached house and a flat were modelled. These dwelling types represent a large part of the UK housing stock.

Hypotheses concerning the dwelling characteristics (detached house and flat), the weather data, the location, the occupancy, the production of contaminants, the user behaviour and the ventilation components were made and are listed in section 2.

The IAQ achieved with a number of ventilation systems with or without DCV were assessed using relative humidity, (total) volatile organic compounds and carbon dioxide, after which the energy saving of a particular DCV system was determined with respect to reference systems 1, 2, 3 and 4.

Three main contaminants affecting the IAQ were modelled:

- Water vapour (H_2O) with production rates derived from BS5250:2002 (XI) and from references (VIII-X);
- Total volatile organic compounds (TVOC) with an emission rate of 0.3 mg/(h.m²) in dry and wet rooms according to ADF;
- Carbon dioxide (CO_2) with production rates derived from the standard CEN/TR 14788 (XII), EN 15665 (XVII) and from references (II&VII).

2 MODEL BUILD-UP

The reference residential ventilation and DCV systems were assessed using the multi-zone airflow modelling software Contam, which was developed by NIST (USA). The software Contam was used in several scientific research dealing with DCV and forms also the basis for the Belgian DCV assessment method (I-VII).

In Contam, each room of the building represents one zone and a simplified humidity buffering model (BLDM) is included. The simulation was run with 5 minutes intervals. Post-processing of the modelling results was done by means of Excel.

Similar to the study of Palmer et al. (I), two houses, a detached one and a flat were modelled. The detached house with a 4-person family was supposed to be situated in a village, while the flat with a couple was located in a city centre. Impact of orientation was taken into account by changing the wind direction every 2 weeks by 90°. Simulations were performed for 5 air permeabilities: 0.6; 2.5; 5; 7.5 and 10 (m³/h)/m² and for the 2 types of dwellings (parameters can be found in Table 1).

Fixed simulation parameters were:

- building location: London (Gatwick)
- outdoor climate (temperature, RH, wind speed and wind direction): TRY iwec
- outdoor CO_2-concentration: 400 ppmv
- indoor air temperature: overall 20°C
- mechanical duct length: 3 or 4 m
- mechanical duct diameter: 125 mm
- inner walls and doors are air tight, with the exception of the transfer openings
- ventilation effectiveness: 1 or perfect mixing as supposed in ADF

The wind pressure coefficients on the different facades and the roof were derived from the "AIVC guide to ventilation" (XIV).

Total air flow rate due to air permeability was derived from the total envelope surface in case of the detached house and only from the vertical external walls in case of the flat. That air permeability was distributed over the vertical external walls, proportionally with the room external wall surface.

The total number of simulations per ventilation systems was 10 (2 houses x 5 air permeabilities). All simulations were run over the typical heating season in UK, which is from 1st October to 31th May or 243 days (heating period SAP, Table 9D). It corresponds to 5,832 hours. To stabilise simulations, the simulation was starting on 1st September. Monthly averaged RH values were calculated on a 30 days basis.

Table 1: Model parameters

Parameter	Detached house	Terraced flat
Terrain roughness	α = 0.313; z_{bound} = 60 m Obstacles at distances of less than a few times building H	α = 0.377; z_{bound} = 80 m City centre
Volume	336 m³	168 m³
Number of floors	2	1
Floor surface	2 x 70 m² or 140 m²	70 m²
Envelope area	303.2 m²	269.6 m²
Envelope area for permeability	303.2 m²	48 m² (facades)
Floor to ceiling height	2.4 m	2.4 m
Floor levels	0 and 1	1 (mid floor)

3 DCV PERFORMANCE ASSESSMENT

3.1 Performance assessment with respect to IAQ

A DCV system was accepted as being equivalent to the reference residential ventilation systems when the same criteria as described thereafter were fulfilled for the detached house and the flat and for all of the 5 air permeabilities considered. Those criteria are either included in ADF, either derived from Contam simulations performed on the 4 reference ventilation systems.

- **RH**:
  The average indoor air RH values per wet room for a certain air permeability ≤
  RH values specified in table A2 of ADF:
  average per month ≤ 65%
  average per week ≤ 75%
  average per day ≤ 85%
  average over 8 hours ≤ 90% (additional requirement with respect to ADF as suggested by BRE)

  Exceeding the threshold values for up to 58 hours for the whole dwelling (< 1% of the heating season) is allowed because high humidity levels during short periods are neither harmfull for the building nor for the occupants.

- **TVOC:**
  (1) According to ADF, exposure to total TVOC levels should not exceed ≤ 300 µg/m³ averaged over 8 hours.

  Contam simulations revealed that in most cases reference systems don't comply with the above performance criterion.

  Therefore, the above criterion was not used. Instead, the following criterion was used to assess the IAQ with respect to TVOC. This new criterion is based on the time which the threshold value was exceeded multiplied by the concentration the threshold value was exceeded. Since the IAQ of system 1 is clearly worse compared to other reference systems and since the TVOC criterion is not applicable to extract ventilation in Part F, System 1 was neglected to set the threshold value.

  (2) Cumulative exposure to TVOC-concentration (µg/m^3).h/pers) over 300 µg/m³ of the DCV system for a certain air permeability ≤
  cumulative exposure to TVOC-concentration (µg/m^3).h/pers) over 300 µg/m³ of the worst reference system taken into account (among systems 2, 3 and 4) which equals 370,000 (µg/m^3).h/pers

- **CO_2:**
  Cumulative exposure to CO_2-concentration (ppm.h/pers) over 1,200 ppm of the DCV system for a certain air permeability ≤
  cumulative exposure to CO_2-concentration (ppm.h/pers) over 1,200 ppm of the worst reference system which equals 1,465,000 ppm.h/pers

The CO_2 threshold was also derived from the Contam simulations for the reference systems 2, 3 and 4 and the results for reference system 1 were also not taken into account following the same reasoning as for TVOC, as there is no threshold mentioned in Part F.

When a DCV system complies with all 3 criteria for all 5 air permeabilities and both types of dwellings, the energy reduction coefficient of the DCV system for lower heat losses and fan consumption can be calculated.

3.2 Performance assessment with respect to energy

DCV affects the ventilation heat losses as well as the fan power consumption.

Ventilation heat losses

The ventilation heat losses of the DCV system were determined for an air permeability of 0 (m³/h)/m², since the effect of infiltration & exfiltration is already taken into account in the SAP calculation (VIII, X). This extrapolation from the 5 modelled air permeabilities to an air permeability of 0 (m³/h)/m² is done for the 4 reference residential ventilation systems as well as for the DCV systems under investigation. The determination coefficient of this extrapolation must be at least 0.95. When lower than 0.95, non-linear regression must be used.

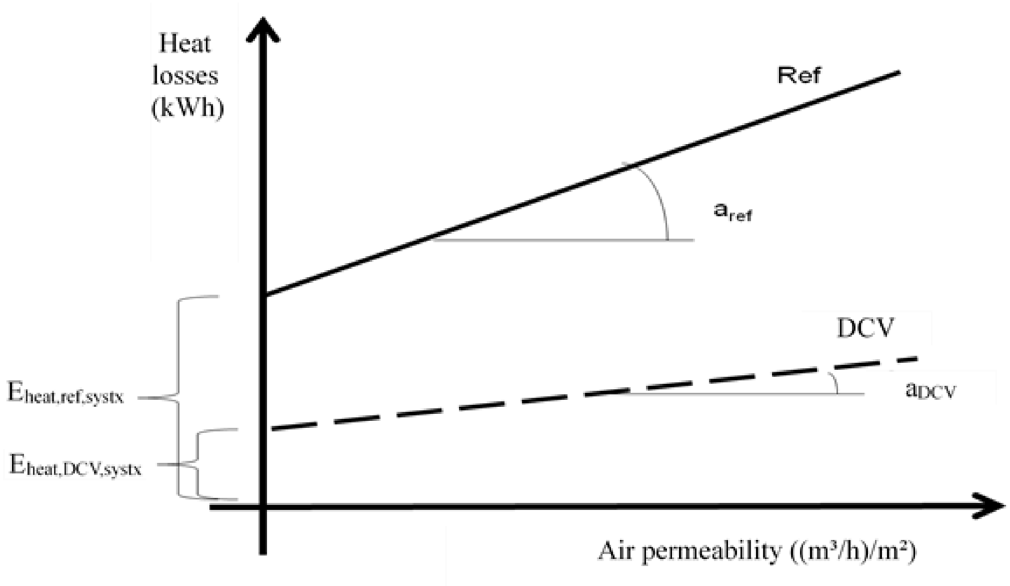


Figure 1: Principle of determination

Consequently, the energy reduction factor of a particular DCV system can be determined as follows:

- The heat losses of the four reference systems is expressed as $E_{heat,ref,systx}$ with x equal to 1, 2, 3 or 4.
- The heat losses of the DCV system is expressed as: $E_{heat,DCV,systx}$.
- The energy performance of the DCV system for the detached house and the flat with respect to heat losses is compared with the energy performance of the same type of reference system to determine the so-called heating reduction factor of the DCV system

$$f_{\text{red,heat,house,DCV,systx}} = \frac{E_{\text{heat,DCV,systx}}}{E_{\text{heat,ref,systx}}} \qquad (1)$$

- The heating reduction factors for the detached house and the flat are averaged to become a single heating reduction factor:

$$f_{\text{red,heat,DCV,systx}} = (f_{\text{red,heat,detached house,DCV,systx}} + f_{\text{red,heat,flat,DCV,systx}})/2$$

Fan consumption

The reduction in fan consumption of the DCV system is derived from the specific fan power values listed in the SAP Product Characteristics Database (PCDB).

For air flow rates lower than 21 l/s, the SFP value is derived as follows:

- The minimum reduced ventilation rate is 1.4 l/s per habitable and wet room. The minimum total reduced ventilation rate at the supply and extract side is found in the flat, i.e. 2.8 l/s (2 wet rooms of 1.4 l/s). Due to the higher number of dry and wet room in the detached house, the total reduced ventilation rate for the detached house is higher than 2.8 l/s. This air flow rate of 2.8 l/s was also considered in Table 2, as an extension of the SAP PCDB values.

- The SFP could be measured at minimum 2.8 l/s within the SAP measurements. When 2,8 l/s is not achievable, the SFP of the lowest air flow rate can be measured. If not measured, **4 x SFP at 21 l/s** is taken, as a common value derived from fan characteristics (see Table 2). Intermediate SFP values are derived from linear interpolation between the power values.

Table 2: SFP as a function of air flow rate

		Kitchen + n wet rooms					
		n=1	**n=2**	**n=3**	**n=4**	**n=5**	**n=6**
Air flow rate (l/s)	2.8	21	29	37	45	53	61
SFP (non DCV mode) (W/(l/s))	4*X1	X1	X2	X3	X4	X5	X6
SFP (DCV mode) (W/(l/s))	f*4*X1	f*X1	f*X2	f*X3	f*X4	f*X5	f*X6

The fan consumption (in kWh) in DCV mode is calculated as the sum of the airflows (in l/s) per time step during the heating season multiplied with the corresponding SFP (in W/(l/s)).

The fan power consumption during the heating season is extrapolated to a yearly fan consumption. In the case of DCV systems controlled on RH values, the DCV fan power consumption outside the heating season is considered as equal to the reference system's.

The reduction factor for fan consumption is defined as:

$$f_{\text{red,fan,house,DCV,systx}} = \frac{\text{fan consumption in DCV mode averaged over the 5 air permeability's (kWh)}}{\text{fan consumption not in DCV mode averaged over the 5 air permeability's (kWh)}} = \frac{E_{\text{fan,DCV,systx}}}{E_{\text{fan,non DCV,systx}}} \quad (2)$$

Then, the fan reduction factors for the detached house and the flat are averaged to become a single fan reduction factor:

$$f_{\text{red,fan,DCV,systx}} = (f_{\text{red,fan,detached house,DCV,systx}} + f_{\text{red,fan,flat,DCV,systx}})/2$$

Finally, the fan reduction factor is used to determine the SFP values of the DCV system as a function of the number of wet rooms, as shown in **Error! Reference source not found.**:

$$SFP\ (DCV\ mode,systx) = f_{red,fan,DCV,systx}\ \ SFP\ (Non\ DCV\ mode)$$

4 DCV SYSTEMS MODELLED

Three examples of DCV systems (DCV3a, DCV3b and DCV3c) are modelled to show how the IAQ and energy performance of a DCV system with respect to the reference system is assessed. All three DCV systems are of type 3, which means that the air is supplied naturally and the air is extracted mechanically. Relative humidity detection, presence detection (in toilets) and CO_2 sensors are used to design the following DCV systems.

- DCV3a: natural supply with local humidity controlled mechanical extract
- DCV3b: local humidity controlled natural supply with local humidity controlled mechanical extract
- DCV3c: natural supply with local CO_2 and humidity controlled mechanical extract.

The air supply rates are designed according to a reference system 3 with background ventilators for all air permeabilities (no alternative guidance).

Main characteristics of DCV3a and DCV3b are:

- RH setpoints (30–75% and 30–80 %) are those used in practice (50-65% for air supply)
- Reduced ventilation rates are higher than the minimum reduced rates of 1.4 l/s
- Maximum high rates are higher than minimum high rates of ADF
- The air supply of DCV3b is also controlled on humidity.

The differences between DCV3c and DCV3a are:

- Lower reduced and lower high rates
- Supplementary control on CO_2 in the living room and the master bedroom. These CO_2 sensors impacts on the total extract from all wet rooms.

Results revealed that the three DCV systems comply with the general DCV requirements as set out in §3, and therefore modelling of the DCV system is allowed. A heat and fan power consumption reduction factor can be determined.

5 RESULTS

5.1 Ventilation heat losses

As for the reference systems, the ventilation heat losses of DCV3a, 3b and 3c were extrapolated to an air tightness of 0 (m³/h)/m² (see **Error! Reference source not found.**) and compared with the corresponding value for reference system 3. The ratio of both gives the heating reduction factor $f_{red,heat,DCV,syst3}$, for the detached house and the flat, which is finally averaged to a value of 0.89; 0.83 and 0.78 for DCV3a, 3b and 3c respectively, as shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

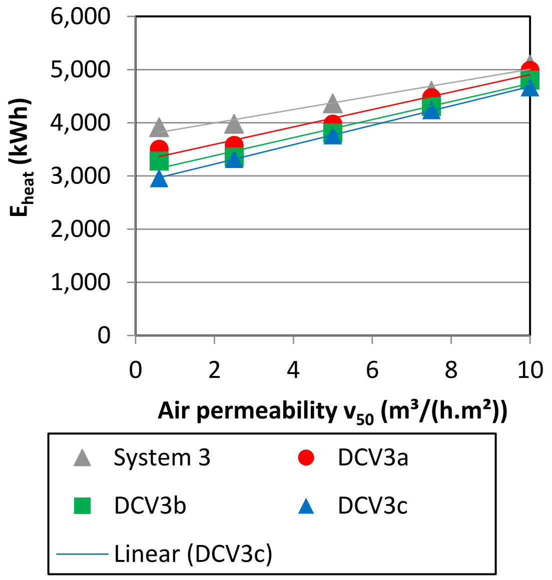
This means that the ventilation losses of the proposed DCV3a, 3b and 3c system are 11%, 17% and 22% lower than the reference system 3.

5.2 Fan consumption

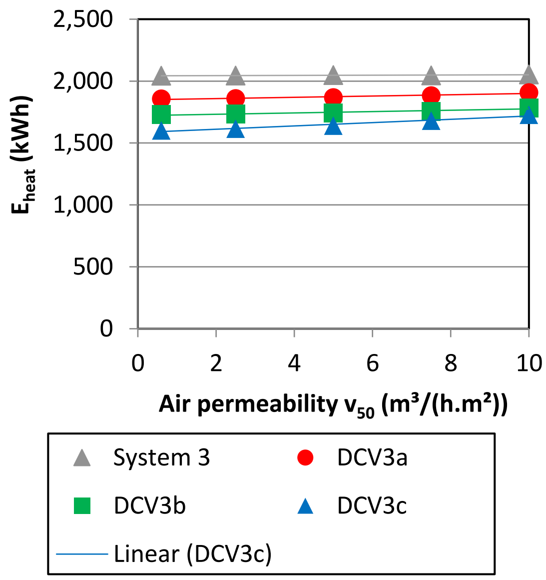
Based on the assumption of the SFP of the reference system 3 and similar SFP values for DCV3a, 3b and 3c, the fan power consumption was calculated as a function of air permeability, as illustrated in Figure 3 for the detached house and flat.

As all system are controlled on RH, the fan power consumption of the reference system was taken into account for the period outside the heating season.

Based on the average fan power consumption, a fan reduction factor of 0.97; 0.94 and 0.89 can be calculated for DCV3a, 3b and 3c respectively.



(a) Detached house



(b) Flat

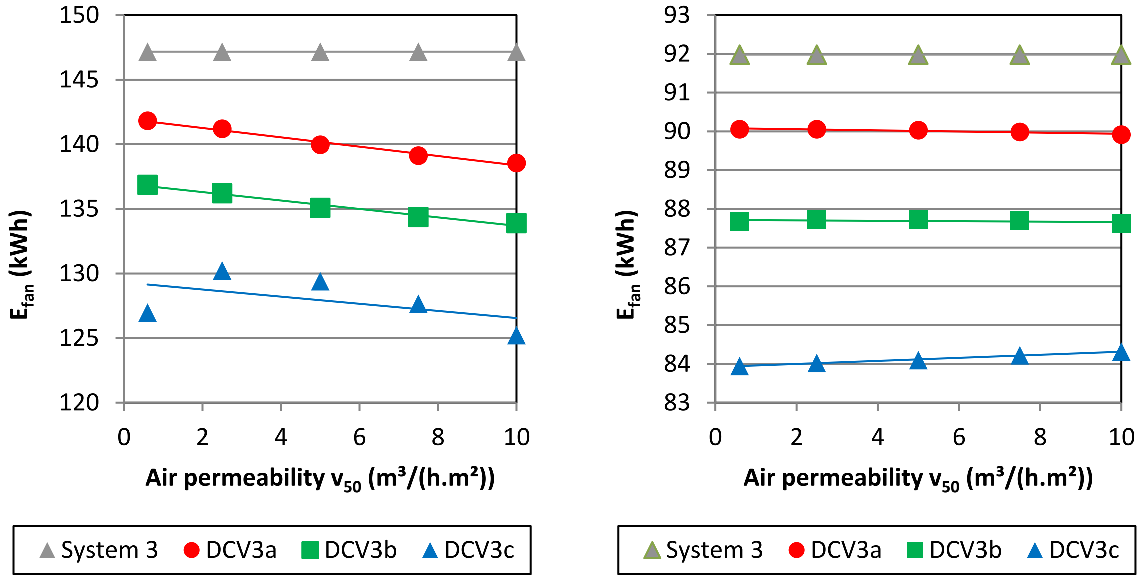
Figure 2: Ventilation heat losses of reference system 3 and DCV3a, 3b and 3c in the detached house

Table 3: Ventilation heat losses of reference system 3, DCV3a, 3b and 3c for the detached house and the flat

	Ventilation heat losses E_{heat} (kWh)	
	Detached house	**Flat**
System 3	3,744	2,044
DCV3a	3,266	1,859
DCV3b	3,043	1,731
DCV3c	2,849	1,584

Table 4: The heating reduction factor of DCV3a, 3b and 3c for the detached house and the flat and the average values

	Heating reduction factor $f_{red,heat,DCV}$ (-)		
	Detached house	**Flat**	**Average**
DCV3a	0.87	0.91	0.89
DCV3b	0.81	0.85	0.83
DCV3c	0.76	0.78	0.77



(a) detached house (b) flat

Figure 3: Fan consumption (whole year) of reference system 3 and DCV3a, 3b and 3c

Table 5: Average fan consumption of reference system 3, DCV3a, 3b and 3c for the detached house and the flat

	Fan consumption E_{fan} (kWh)	
	Detached house	**Flat**
System 3	147	92
DCV3a	140	90
DCV3b	135	88
DCV3c	128	84

Table 6: The fan reduction factor of DCV3a, 3b and 3c for the detached house and the flat and the average values

	Fan reduction factor $f_{red,fan,DCV}$ (-)		
	Detached house	**Flat**	**Average**
DCV3a	0.95	0.98	0.97
DCV3b	0.92	0.95	0.94
DCV3c	0.87	0.91	0.89

6 CONCLUSIONS

- A reliable residential ventilation model and assessment methodology for all 4 reference ventilation systems was built, which can be used to assess all types of ventilation systems using Demand Controlled.
- The energy consumption for heating and fan consumption, expressed as a reduction factor relative to the reference system, are the outputs of the model to be used for the SAP calculation.
- DCV systems can create an equally good or even better IAQ than the reference ventilation systems, while reducing energy consumption for heating and fan power consumption. In that way, DCV has a positive effect to reach EPBD and NZEB goals.
- All 3 example DCV systems modelled comply with the 3 IAQ criteria (relative humidity, TVOC and CO_2). Mean reduction factors for heating up to 77% and fan consumption up to 89% were achieved. Further savings can probably be obtained with optimised systems.
- Simulations showed that different configurations of DCV systems can comply with the 3 IAQ criteria, while the energy performance is better than reference systems. One kind of sensor (RH, CO_2, TVOC, presence in toilets) or a combination of different sensors types allows to ensure IAQ at lower air flow rates, provided the sensors, air flow rates and control setpoints are designed correctly by the manufacturers and appropriate tests

prove their performance and their reliability. Minor site adjustments can be envisaged to adapt to specific layouts when clearly documented in the manufacturers' installation documents. Professionnal commissionning as per industry and manufacturer's guidelines is essential to ensure proper installation.

- The more advanced the DCV system, the higher the potential to improve the energy performance of the system.
- It is inherent to modelling, that small changes in the DCV characteristics can determine whether the IAQ are fulfilled or not (= high sensitivity) and as a consequence, if the system can be recognised as DCV. However, this small changes will also result in small differences in energy performance (= low sensitivity). This means that the model is robust regarding the energy performance, but sensitive regarding the fulfilment of the IAQ criteria. This latter sensitivity is already limited by the general requirements of a DCV system (as described in section 3) and can further be restricted if needed.
- The energy-saving potential of DCV systems in domestic buildings in the UK can be estimated as follows using the examples of DCV Systems 3 described above:
  - Mean heating and fan reduction factor of the DCV system of 0.83 and 0.93, respectively
  - If 50,000 new homes in the UK have a Demand Controlled Ventilation system
  - Boiler / heat distribution efficiency of 80%
  - CO_2-emission factors based on secondary energy consumption of 0.202 kg CO_2/kWh gas and 0.543 kg CO_2/kWh electricity

  ⇒ Yearly reduction of heating gas consumption 35.0 GWh
  ⇒ Yearly reduction of fan electricity consumption 0.46 GWh
  ⇒ Yearly reduction of CO_2-emissions 7,311 tons of CO_2

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