A holistic evaluation method for decentralized ventilation systems

Sven Auerswald*[1, 2], Thibault Pflug[1], Peter Engelmann[1], Nicolas Carbonare[1, 3], Constanze Bongs[1], and Hans-Martin Henning[1, 2]

1 Fraunhofer-Institut für Solare Energiesysteme ISE

Heidenhofstr. 2

79110 Freiburg, Germany

sven.auerswald@ise.fraunhofer.de

2 Albert-Ludwigs-Universität Freiburg

Institut für Nachhaltige Technische Systeme (INATECH)

Emmy-Noether-Straße 2

79110 Freiburg, Germany

3 Karlsruhe Institute of Technology

Fachgebiet Bauphysik und Technischer Ausbau, Fakultät für Architektur

Englerstr. 7, building 20.40

76131 Karlsruhe, Germany

ABSTRACT

The implementation of decentralised ventilation units is growing, especially in the residential retrofit. These systems are typically simple to install on site (usually in the external façade with no additional ductwork) and allow room-by-room control strategies. Until now, decentralised systems are evaluated by applying the same methodologies as for centralised ventilation systems, even though different boundary conditions apply. Some differences are for example:

- thermal bridges through the casing of the ventilation device are more important to consider
- most of the decentralised ventilation systems operate by alternating supply and exhaust airflow through the same flow channel
- they usually need almost no ductwork

Furthermore, the existing mandatory evaluation methodologies (based on the Energy Performance of Buildings Directive, EPBD) are focused on the evaluation of the energy performance. This evaluation of the energy performance is not combined with other aspects, such as e.g. the influence of the ventilation unit on the indoor air quality (CO_2, VOC, among others), the indoor air age distribution, the temperature or the moisture distribution in a room, etc. Within the following paper, a new evaluation method is going to be introduced. The methodology is modular, rating the performance of decentralised ventilation systems related to a variety of aspects such as their energy efficiency, the resulting indoor air quality for a residential use, hygrothermal comfort, etc. The new evaluation method, which is theoretically

introduced here, will later be implemented in a climate-chamber test-facility to evaluate and assess decentralised ventilation systems.

KEYWORDS

Decentralised alternating regenerative ventilation device, heat recovery, IAQ – indoor air quality, ventilation efficiency, hygrothermal comfort, evaluation method, technical regulation

1 SYMBOLS

Dimensions			**Indexes**	
c	Concentration	$mg \cdot m^{-3}$	11	Indoor air
C	Concentration	[unspecified]	12	Extracted air at the outdoor side
E	Energy	J	21	Outdoor air for the supply
f	Any standardisation function	-	22	Supply air indoor
$\dot{m}$	Mass flow	$kg \cdot h^{-1}$	a	Average
n_P	Number	pers	b	Building
P_E	Effective electric power input	W	e	Environment
PPD	Percentage persons dissatisfied		elec	Electric
DR	Draft rate	-	IM	Indoor mixing chamber according to DIBt LÜ-A Nr. 22-2
$PD_{\Delta T}$	Percentage dissatisfied in terms of temperature gradients	-	in	Inflow into the mixing chamber
PD_{CO_2}	Percentage dissatisfied in terms of CO_2-concentration	-	o	Operation
Δp	Pressure drop/difference	Pa	out	Outflow extracted from the mixing chamber
$\dot{V}$	Volume flow	$m^3 \cdot h^{-1}$		
γ	Volume concentration	vol.%	P	Person
ε	Ventilation efficiency	-	ref	Reference
ϑ	Temperature	K	st	Steady-state conditions
x	Mass fraction of water in dry air	–	trans	Transient
η_ϑ	Heat recovery ratio	-	v	ventilation
η_x	Moisture recovery ratio	-		
τ	Nominal time constant or inverse air exchange rate	s		
τ_i	Air age	s		

2 INTRODUCTION

Decentralised residential ventilation (DRV) units are increasingly implemented in buildings. They are especially interesting for the residential retrofit market, where they can for example be implemented in the outer façade of the building, providing heat recovery ventilation with room-by-room control possibilities. The installation is simple and in most cases, no ductwork is required. In Germany in the year 2017, 179 000 DRV with heat recovery were sold, which represented an increase of +21 % compared to the previous year (Bundesverband der Deutschen Heizungsindustrie e. V., pp.3).

The current technical regulations and standards applying to ventilation systems for residential buildings are summarised in EN 13141-7 & -8, EN 13142, DIN 1946-6, DIN V 18599-6, DIBt LÜ-A. Nr. 21 & 22, PHI-Prüfverfahren, EU 1254/2014 and related ones (DIN EN 13141-7; DIN EN 13141-8; DIN EN 13142; DIN 1946-6 Entwurf; DIN V 18599-6; Deutsches Institut für Bautechnik 2018; Holzwarth 2014; Passivhaus Institut 2009; European Commission 2014). These technical regulations and standards have two major drawbacks when it comes to assessing DRV:

- The DRV operating in alternating mode are not represented sufficiently by the existing evaluation methods. These regenerative DRVs operate by reversing the airflow direction in the device every time period to transfer energy from or to a thermal storage, providing recovered heat. The main limits of the current evaluation methods for these devices are their transient behaviour and the fact they are usually façade-integrated. In that sense, it is highly difficult to replicate the real boundary conditions for a laboratory measurement.
- The second aspect is the fact that mechanical ventilation devices are insufficiently evaluated with respect to ventilation efficiency, indoor air quality and a pleasant hygrothermal comfort.

Therefore, this contribution is presenting an approach for a holistic method to assess DRVs on multiple aspects. The aim is to address the need for a more precise quantitative evaluation of all the aspects relevant for DRVs.

3 STATE OF THE ART

As already summarised by Fabian Coydon (2015) the most important physically measureable aspects relevant to evaluate the ventilation performance are the energy efficiency of the devices, the ventilation efficiency, the hygrothermal comfort and the acoustic. For all of these aspects there are several evaluation methods available and accepted for approval procedures of devices or systems closely connected to DRVs. However, they are not combined in a holistic method to evaluate DRVs. The three aspects energy efficiency, hygrothermal comfort and indoor air quality will be reviewed in the following sections.,

3.1 Evaluation of energy efficiency

The overall energy consumption of a ventilation device including a heat recovery is already covered by several evaluation methods. The most relevant in Germany is based on the technical regulation series EN 13141 (Deutsches Institut für Bautechnik 2018)(Deutsches Institut für Bautechnik 2018). In order to authorise the application of regenerative DRVs in Germany, each of them has to be tested according to DIBt Lü-A. Nr. 22-2, which is a

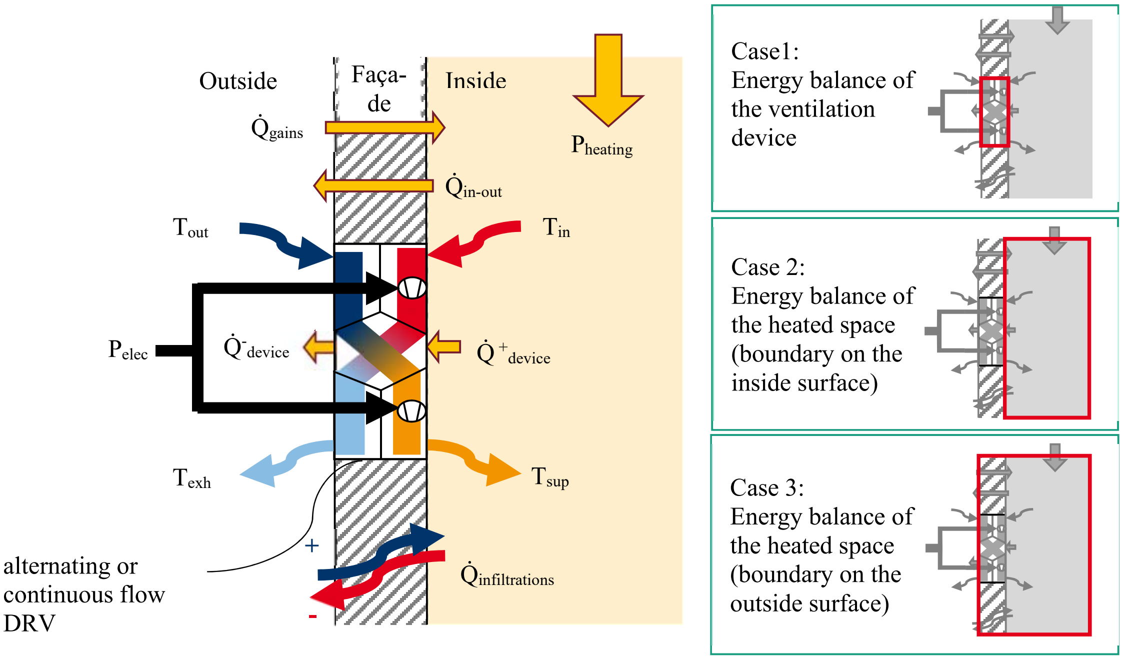

Figure 1 Energy and airflows characterising a façade integrated decentralised ventilation system with heat recovery and boundaries of different energy balances (Coydon 2015, p. 38)

modified EN 13141-8:2014-09 evaluation method. This testing procedure is called “Spülkammerverfahren” (engl. rinse chamber procedure) (Deutsches Institut für Bautechnik 2017). Other evaluation methods or values are e.g. provided by Passivhaus-Institut (Passivhaus Institut 2009). A calorimetric method was also proposed in the dissertation of Fabien Coydon (Coydon 2015, pp.50; Passivhaus Institut 2009, pp.4).

Each one of the heat recovery efficiencies resulting out of these methods for DRVs is based on one of the three energy balances which have already been summarised by Coydon (Coydon 2015, pp.38). The system boundaries for the energy balance can be chosen according to the cases depicted in Figure 1. The energy balances of the evaluation methods DIN EN 13141-8 and PHI 2009 match case 1. The DIBt LÜ-A. Nr. 22-2 is matching case 2 and the proposed method from Coydon case 3.

3.2 Hygrothermal comfort

For the indoor comfort, there is a broad range of technical regulations and standards available to describe hygrothermal comfort itself. In general, these can be distinguished into steady and adaptive comfort models. For the first type the most widespread and accepted methods to describe indoor air comfort are considered to be DIN EN ISO 7730 and DIN 4108-2. EN 15251 and ASHRAE 55 are describing the adaptive models. In terms of the indoor distribution of the temperature, the humidity and the air velocity, the indicators to be chosen are PMV incl. PPD, PD and DR.

3.3 Indoor air quality and air exchange efficiency

Up until now, the indoor air quality is generally considered suitable or sufficient as long as certain air exchange ratios are provided by the ventilation strategy of a building (DIN EN 15251, pp.20–23). As a result, there is hardly any connection to the actual occurring air pollution concentrations. The foundation of this approach is the assumption of perfect mixing of the indoor air. This means in particular, the concentration of pollutants is close to the ducts equal to the concentration in the entire room (DIN EN 15251, pp.33–34). Whether or not this is a sufficient assumption for a particular ventilation strategy is not questioned by these methods. Nevertheless, if the CO_2-concentration and its distribution throughout the room shall be evaluated, EN 15251 refers to EN 13779 to evaluate the ventilation efficiency (DIN EN 15251, pp.34).

4 HOLISTIC METHOD

The holistic evaluation method for domestic ventilation devices presented is based on (Coydon 2015, pp.61). The idea is to combine different aspects and indicators (energetic, hygrothermal, ventilation efficiency, acoustic, etc.) in one single indicator. Since the measurement conditions and equipment to evaluate the acoustic is not compatible with those of the other aspects this work will not focus on it, however the approach will be adaptable to integrate this aspect in a next stage. The idea of the new method will following template Equation (4-1):

$$\Sigma_{\mathrm{VD}}=\sum_{i=1}^{I}\left[\frac{w_i}{\sum_i^I w_i}\cdot f_i\left(\mathbf{x}_j\right)\right] \qquad \text{with } \{i,j\}\in\mathbb{N}^{+} \mid [1;I],\ \sum_i^I w_i \in[0;100] \tag{4-1}$$

Σ_{VD} total score achieved by the ventilation device
$f_i(\mathbf{x}_j)$ standardisation function for the indicator $\mathbf{x}_j$
w_i weighting factor for indicator i

I	total number of indicators combined in the holistic method

The standardisation functions $f_i(\mathbf{x_i})$ will represent one crucial aspect for the evaluation each. Their role is to be able to compare different indicators coming from different fields. Examples for these functions will be similar to that in equation (4-2). As far as possible, these functions will reference to already existing functions and evaluation procedures with a broad range of acceptance like those mentioned in 3 State of the art.

$$f_i(\mathbf{x}_j) = [0;100] \in \{\eta_\vartheta, \mathrm{PPD}, \mathrm{DR}, \mathrm{PD}_{\Delta T}, \varepsilon_v, \mathrm{PD}_{CO_2}\} \forall \{i,j\} \in \mathbb{N}^+ \tag{4-2}$$

η_ϑ	mean seasonal heat recovery ratio based on several typical cases for a whole year
PPD	percentage persons dissatisfied
DR	draft rate
$\mathrm{PD}_{\Delta T}$	percentage dissatisfied in terms of vertical temperature gradients
ε_v	ventilation efficiency in a representative horizontal plane in the room
PD_{CO_2}	percentage dissatisfied with respect to the CO_2-concentration

The second type of values necessary for the equation (4-1) is the weighting factor. These will be based on a representative survey. Architects, building planers, building operators and actual users will be asked. The survey will primarily be focused on the aspects mentioned above in order to have a relevant basis to establish the weighting coefficients.

4.1 Evaluation of energy efficiency

The methods mentioned in 3.1 to evaluate the energy performance of DRVs will be the ones taken into account for the holistic. Nevertheless, it might still be possible to consider further methods for the energy efficiency to integrate into the holistic method if it is necessary in future.

The EU 1254/2014 requires at least a temperature exchange rate η_ϑ between extract and supply air flow measured with balanced mass flow, under standard air conditions (20 °C, 101325 Pa) and an indoor-outdoor temperature difference of 13 K (European Commission 2014, pp.5). Depending on the requirements for the temperature sensor position EU 1254/2014 can be equal to η_ϑ in EN 308 (DIN EN 308, pp.3). But more importantly η_ϑ in EN 13141-8 equals EU 1254/2014 in the case where the mass flow ratios of the extract and supply air are perfectly balanced and the temperature sensor positions are defined to be at the in- and outlet of the entire housing of the DRV (DIN EN 13141-8, pp.21–26). The following Table 1 summarizes the pros and cons of the different evaluation methods for DRVs.

Table 1: Evaluation methods to evaluate the energy efficiency of decentralised façade-integrated ventilation systems with heat recovery.

Source and equation	Pros	Contras
EU 1254/2014 (European Commission 2014) $\eta_\vartheta = \frac{\vartheta_{22}-\vartheta_{21}}{\vartheta_{11}-\vartheta_{21}}$	- Broad range of values to indicate the energy consumption characteristics - Widespread acceptance - Open to technical and scientific improvements - Provides an annual m²-specific energy consumption as well - Internal leakages need to be evaluated for 100 Pa pressure - External leakages need to be evaluated	- Because of the legislative character of the regulation: • no details concerning the required measurement uncertainties and procedures • the values required can be based on different evaluation methods

	for {-250, 250} Pa	
DIN EN 13141-8:2014-09 (DIN EN 13141-8) $\eta_\vartheta=\frac{\vartheta_{22}-\vartheta_{21}}{\vartheta_{11}-\vartheta_{21}}\cdot\frac{\dot{m}_{22}}{\dot{m}_{11}}$ $\eta_x=\frac{x_{22}-x_{21}}{x_{11}-x_{21}}\cdot\frac{\dot{m}_{22}}{\dot{m}_{11}}$	- influences of hygrothermal differences are take into account for: • temperature • humidity - Specific, mandatory and optional measurement conditions - $\dot{V}, \Delta p$ – curve has to be specified according to (DIN EN 13141-4) and (EVS EN ISO 5801) for over and under pressure {-20, 0, 20} Pa - P_E has to be specified at least for the maximum, the minimum and the reference air flow - the allowed sensor uncertainties are specified - $\eta_{\vartheta,su}$ multiplies the η_t by the ratio of the mass flow rates, which leads to a correction for slightly unbalanced DRVs - considers internal and external volume flow leakages and defines a maximum allowed leakage rate	- temperature, humidity and electric power input are not used together in a actual heat recovery ratio - thermal bridges are not specifically evaluated - contrary statements for the measurement setup: • ambient temperature of the device = dry bulb temperature of the extract air ⇒ forced thermal boundary condition for the housing • parts of the device in the façade have to be well insulated ⇒ temperature gradient through the façade
DIBt LÜ-A. Nr. 22-2 as a variation of DIN EN 13141-8:2014-09 (Mirring and Busler 2014) $\eta_\vartheta=\frac{\vartheta_{IM,out,trans}-\vartheta_{IM,out,\mathbf{st}}}{\vartheta_{IM,in}-\vartheta_{IM,out,\mathbf{st}}}$	- influences of hygrothermal differences are take into account for: • temperature - specific mandatory measurement conditions according to (DIN EN 13141-8) - $\dot{V}$,Δp-curve has to specified according to DIN EN ISO 5801:2012-11 for over and under pressure {-20, 0, 20} Pa - P_E has to be specified at least for the maximum, the minimum and the reference air flow - Applies EN 13141-8 for internal and external leakages	- temperature, humidity and electric power input are not used together in a actual heat recovery ratio - influences of hygrothermal gradients are not indicated for: • humidity - η_ϑ(DIBt) does not multiply by the ratio of the mass flow rates of the DRVs ⇒ no correction for slightly unbalanced DRVs sensor uncertainties are not indicated - uncertainties of the results are not indicated - evaluation of thermal bridges is not possible
Passivhaus-Institut requirements for ventilation devices < 600 m³/h (Passivhaus Institut 2009) $\eta_\vartheta=\frac{\vartheta_{11}-\vartheta_{12}+\frac{P_{el}}{\dot{m}\cdot c_p}}{\vartheta_{11}-\vartheta_{21}}$	- influences of hygrothermal gradients are indicated for: • temperature - specific mandatory measurement conditions according to (Passivhaus Institut 2009) - $\dot{V}$,Δp-curve has to specified for over and under pressure {-300, 300} Pa - P_{el} has to be specified for 100 Pa pressure difference	- temperature, humidity and electric power input are not used together in a actual heat recovery ratio - influences of hygrothermal differences are not indicated for: - humidity - mass flow rates are not part of η_ϑ(PHI) representing the heat recovery ratio for EU 1254/2014 (European Commission 2014)

		- sensor uncertainties are not indicated - uncertainties of the results are not indicated - thermal bridges are not specifically evaluated
Dissertation Fabien Coydon (Coydon 2015) $\eta_{\vartheta}=\frac{E_{ref,v}-E_{heating,v}-E_{elec}}{E_{ref,v}}$	- Reference condition is not just representing mass flows entering and leaving the black box of the device, or a reference volume of the indoor air, but a whole reference room without any ventilation device. - Considered effects • the heat from the fans received by the supply and exhaust airflows • heat exchange through the envelope of the ventilation device • Imbalance between the supply and exhaust airflows • Considers internal and external leakages • Influence of both airflows on the thermal performance of the building envelope	- There are hardly any specifications regarding the measurement procedures and equipment necessary for the evaluation. - An evaluation of just one type of ventilation devices according to this method would rise the question if the results were still comparable to the results of evaluation methods for other ventilation devices.

4.2 Hygrothermal comfort

Even though ventilation devices are not yet evaluated directly in terms of their impact to the indoor comfort, there is a broad range of technical regulations and standards available to describe hygrothermal comfort itself. As mentioned in 3.2 Hygrothermal comfort the evaluation methods for this aspect can be distinguished into steady and adaptive comfort models. Table 2 and Table 3 are summarising the basic concepts of these models.

Table 2: Summary of the referenced steady comfort models (DIN EN ISO 7730; DIN 4108-2)

Source	**ISO 7730**	**DIN 4108-2**
reference values	Proposed percentage dissatisfied PPD - Activity (Office, class room) = 1,2 met - Clothing factor • heating period = [0.7; 1.1] clo • cooling period = [0.3; 0.7] clo - Operative indoor temperature limit: • heating period $\vartheta_o = 24.5$ °C • cooling period $\vartheta_o = 22.0$ °C - humidity: $\varphi_{11} = 50$ %rh - indoor air velocity: $\{v_{11,I}, v_{11,II}, v_{11,III}\}$ in $m \cdot s^{-1}$ • heating period {0.1; 0.16; 0.21} • cooling period {0.12; 0.19; 0.24} ⇒ evaluation values: PPD, $PD_{\Delta T}$, DR	Operative indoor temperature limit: - $\vartheta_o = 25$ °C for $\vartheta_{e,a} < 16.5$ °C - $\vartheta_o = 26$ °C for $16,5\ °C \leq \vartheta_{e,a} \leq 18\ °C$ - $\vartheta_o = 27$ °C for $18\ °C < \vartheta_{e,a}$
Comfort classes	I: 94% acceptance ±1 °C II: 90% acceptance ±2 °C II: 85% acceptance ±3 °C	No

Table 3: Summary of the referenced adaptive comfort models (DIN EN 15251; ANSI/ASHRAE Standard 55)

Source	**EN 15251**	**ASHRAE 55**
Reference values	- Activity (living space, seated) = 1.2 met - Clothing factor • heating period = 1 clo • cooling period = 0.5 clo - Operative indoor temperature limit $\vartheta_o = 0.33\ \vartheta_{e,a} + 18.8$ - humidity: $\varphi_{11} = 50$ %rh ⇒ evaluation value: PPD Reference to (ISO 7730) - draft - vertical temperature gradient - floor temperature - asymmetry in radiation temperature ⇒ evaluation values: DR, $PD_{\Delta T}$	- Activity (living space, seated) = [1; 1.3] met - Clothing factor = [0.5; 1] clo - Operative indoor temperature limit $\vartheta_o = 0.31\ \vartheta_{e,a} + 17.8$ - indoor air velocity: $v_{11} < 0.2\ m \cdot s^{-1}$ - humidity: $X_{11} \leq 0.012$ kg(w) $kg(da)^{-1}$ ⇒ evaluation values: PPD, $PD_{\Delta T}$, DR
Comfort classes	I: 94% acceptance ±2 °C II: 90% acceptance ±3 °C II: 85% acceptance ±4 °C	I: 90% acceptance ±2.5 °C II: 80% acceptance ±3.5 °C

4.3 Indoor air quality and air exchange efficiency

For both aspects 3.3 Indoor air quality and air exchange efficiency already mentions DIN EN 15251. Even though this method is not yet applied for evaluating the IAQ and air exchange efficiency provided because of ventilation devices it will be the central technical standard considered for the further evaluation. The first important regulation applied out this standard are the satisfaction categories for CO_2-concentration in Table 4 (DIN EN 15251, pp.31 + 34).

Table 4: necessary volume flow values considered to provide certain satisfaction categories for the CO_2-concentration (DIN EN 15251, pp.31 + 34)

Cat.		**Volume flow per person (in single office)**	**Specific volume flow for building with low air pollution**	**Allowed CO_2-concentration above outdoor level**
	PD_{CO_2} in %	$\dot{V}_P \cdot n_P^{-1}$ in $l\ s^{-1}\ pers^{-1}$	$\dot{V}_B \cdot A_{11}^{-1}$ in $l\ s^{-1}\ m^{-2}$	in ppm
I	15	10	1	350
II	20	7	0.7	500
III	30	4	0.4	800
IV	>30	<4	<0.4	>800

As already mentioned EN 15251 refers to EN 13779 to evaluate the ventilation efficiency (DIN EN 15251, pp.34). However, EN 13779 is just one possibility to master the evaluation of the ventilation efficiency. Table 5 provides a summary of the selected evaluation methods to evaluate the ventilation effectiveness.

Table 5: Comparison of methods to evaluate the ventilation effectiveness (Rietschel and Fitzner 2008; EVS EN ISO 16000-26; DIN EN 13779; DIN ISO 16000-8)

Source and equation	**Pros**	**Contras**
ISO 16000-26 Ventilation efficiency $\varepsilon_v = \frac{\gamma_{12,a} - \gamma_{21,a}}{\gamma_{11,a} - \gamma_{21,a}}$	- Examination and determination of the average gas concentration throughout a relevant space/plane in the room - Simple to implement	- Calculation based on steady or instantaneous values ⇒ the reaction of a ventilation device to a sudden variation is not clear, and alternating DRVs may not be assessed correctly. - Limited evidence about the distribution of the pollutant - No statement about the user acceptance level
EN 13779 Ventilation efficiency $\varepsilon_v = \frac{c_{12,a} - c_{21,a}}{c_{11,a} - c_{21,a}}$	- Examination and determination of the average gas concentration throughout a relevant space/plane in the room - Simple to implement	
Rietschel & Fitzner Contaminant removal effectiveness (CRE) $\varepsilon_v = \frac{C_{12,st,a}}{C_{11,st,a}}$	- Examination and determination of the average gas concentration throughout a relevant space = room - Simple to implement	
Rietschel & Fitzner Local air quality index $\varepsilon_v = \frac{C_{12,st,a}}{C_{11,st}}$	- Examination and determination of the a specific point in a relevant space/plane in the room - Simple to implement	
Rietschel & Fitzner + ISO 16000-8 Local or average air exchange efficiency $\varepsilon_v = \frac{\tau}{\tau_i}$, with $\tau_i=\{\tau_{11}, \tau_{12}\}$ $\tau_i = \int_0^\infty \frac{C_i(t)}{C_i(t=0)} dt$	- Examination and determination of • a specific point in a relevant space/plane in the room possible • the average concentration in the room for each time step - evaluation of the transient behaviour of the concentration • step-up behaviour • step-down behaviour • entering and exit point of the steady state behaviour - Evaluation of the transient distribution in the room possible by installing several points of measurement	- No statement about the user acceptance level

5 CONCLUSION

In this contribution, a new holistic method (HM) to evaluate Decentralised Residential Ventilation (DRV) units are presented. The method combines different aspects such as energy efficiency, hygrothermal comfort, ventilation efficiency and indoor air quality (IAQ). The method is modular and other aspects could be added later on. For each aspect, a selection has been made among existing evaluation methods. The next steps are:

- Construction of a test chamber (TC) to evaluate the energetic, comfort, IAQ and ventilation efficiency of DRVs.
- Using the TC to evaluate different existing DRVs according to the above methods.
- Choice of the most suited evaluation methods for each aspect, to be used in the HM.

- Apply the HM to the different DRVs and compare the DRVs performance.

6 AKNOWLEGEMENT

This work was funded by the BMWi (Germany ministry of economic affairs) under the auspices of grant 03ET1540B („Modulierende Sole-Wärmepumpe mit Mehrquellensystem und dezentrale Lüftungsanlagen“ (HEAVEN project)), which is part of the initiative: „Verbundvorhaben LowEx-Konzepte für die Wärmeversorgung von sanierten Mehrfamilien-Bestandsgebäuden (LowEx-Bestand)“.

7 REFERENCES

Coydon, Fabien. 2015. “Holistic evaluation of conventional and innovative ventilation systems for the energy retrofit of residential buildings.” Dissertation, Fraunhofer-Institut für Solare Energiesysteme Freiburg im Breisgau, Karlsruher Institut für Technologie (KIT).

Deutsches Institut für Bautechnik. 2017. “Vorläufiges Prüfprogramm: für "Dezentrale Lüftungsgeräte mit Regenerativ-Wärmeübertrager und alternierender Ventilatordrehrichtung" : Übergangsfristen.” News release. February 13, Accessed June 03, 2018. https://www.dibt.de/de/Fachbereiche/data/Uebergangsfristen_Dezentrale_Lueftungsgeraete.pdf.

DIN EN 15251:2007-08 - *Eingangsparameter für das Raumklima zur Auslegung und Bewertung der Energieeffizienz von Gebäuden – Raumluftqualität, Temperatur, Licht und Akustik; Deutsche Fassung EN 15251:2007*, ICS 91.140.01. Berlin: Beuth Verlag GmbH.

EVS EN ISO 5801:2008-10 - *EN ISO 5801:2008-10 - Industrial fans - Performance testing using standardized airways*, ICS 23.120. Tallin: Eesti Standardikeskus.

DIN V 18599-6:2016-10 - *Energetische Bewertung von Gebäuden – Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung – Teil 6: Endenergiebedarf von Lüftungsanlagen, Luftheizungsanlagen und Kühlsystemen für den Wohnungsbau*, ICS 91.120.10; 91.140.10; 91.140.30. Berlin: Beuth Verlag GmbH.

DIN EN ISO 7730:2006-05 - *Ergonomie der thermischen Umgebung – Analytische Bestimmung und Interpretation der thermischen Behaglichkeit durch Berechnung des PMV- und des PPD-Indexes und Kriterien der lokalen thermischen Behaglichkeit (ISO 7730:2005); Deutsche Fassung EN ISO 7730:2005*, ICS 13.040.20; 13.180. Berlin: Beuth Verlag GmbH.

DELEGIERTE VERORDNUNG (EU) Nr. 1254/2014 DER KOMMISSION - vom 11. Juli 2014 - zur Ergänzung der Richtlinie 2010/30/EU des Europäischen Parlaments und des Rates im Hinblick auf die Kennzeichnung von Wohnraumlüftungsgeräten in Bezug auf den Energieverbrauch. EU 1254/2014. European Commission. Amtsblatt der Europäischen Union 27. July 11, Accessed August 03, 2017.

Holzwarth, Carmen. 2014. “Hinweis für Antragsteller: Neues aus dem Arbeitsgebiet "Lüftungsgeräte" des Referats III 5: Änderungen in der Nachweisführung in Zulassungsverfahren für Lüftungsgeräte.” News release. September 30, Accessed June

01, 2018. https://www.dibt.de/de/Fachbereiche/data/Ref_III_5_%C3%84nderungen_Nachweisf%C3%BChrung_in_Zulassungsverfahren_f%C3%BCr_L%C3%BCftungsger%C3%A4te.pdf.

EVS EN ISO 16000-26:2012-08 - *Indoor air - Part 26: Sampling strategy for carbon dioxide (CO2) (ISO 16000-26:2012)*, ICS 13.040.20. Tallin: Eesti Standardikeskus.

DIN ISO 16000-8:2008-12 - *Innenraumluftverunreinigungen – Teil 8: Bestimmung des lokalen Alters der Luft in Gebäuden zur Charakterisierung der Lüftungsbedingungen (ISO 16000-8:2007)*, ICS 13.040.20. Berlin: Beuth Verlag GmbH.

DIN EN 13142:2013-06 - *Lüftung von Gebäuden - Bauteile/Produkte für die Lüftung von Wohnungen - Geforderte und frei wählbare Leistungskenngrößen; Deutsche Fassung EN 13142:2013.* Berlin: Beuth Verlag GmbH.

DIN EN 13141-8:2014-09 - *Lüftung von Gebäuden - Leistungsprüfung von Bauteilen/Produkten für die Lüftung von Wohnungen- Teil 8: Leistungsprüfung von mechanischen Zuluft„ und Ablufteinheiten ohne Luftführung (einschließlich Wärmerückgewinnung) für ventilatorgestützte Lüftungsanlagen von einzelnen Räumen; Deutsche Fassung EN 13141-8:2014*, ICS 91.140.30. Berlin: Beuth Verlag GmbH.

DIN EN 13141-4:2011-09 - *Lüftung von Gebäuden - Leistungsprüfungen von Bauteilen/Produkten für die Lüftung von Wohnungen - Teil 4: Ventilatoren in Lüftungsanlagen für Wohnungen*, ICS 91.140.30. Berlin: Beuth Verlag GmbH.

DIN EN 13141-7:2011-01 - *Lüftung von Gebäuden – Leistungsprüfungen von Bauteilen/Produkten für die Lüftung von Wohnungen – Teil 7: Leistungsprüfung von mechanischen Zuluft- und Ablufteinheiten (einschließlich Wärmerückgewinnung) für mechanische Lüftungsanlagen in Wohneinheiten (Wohnung oder Einfamilienhaus); Deutsche Fassung EN 13141-7:2010*, ICS 91.140.30. Berlin: Beuth Verlag GmbH.

DIN EN 13779:2007-09 - *Lüftung von Nichtwohngebäuden – Allgemeine Grundlagen und Anforderungen für Lüftungs- und Klimaanlagen und Raumkühlsysteme; Deutsche Fassung EN 13779:2007*, ICS 91.140.30. Berlin: Beuth Verlag GmbH.

"Marktentwicklung Wärmemarkt Deutschland 2017." News release, Accessed June 22, 2018. http://www.bdh-koeln.de/fileadmin/user_upload/pressemitteilungen_pdf/Marktentwicklung_Waermemarkt_2017.pdf.

Mirring, Heiko, and Thomas Busler. 2014. "Bericht WRG 375 DIBt: wrg375 Inventer iV12-Smart wrg375 Inventer iV12-Smart Bericht DIBt-LÜ-A-22-2-141217-mrkl." Accessed May 30, 2018. http://www.zeroenergia.it/download/wrg375%20Inventer%20iV12-Smart%20Bericht%20DIBt-LU-A-22-2-141217-mrkl.pdf.

"Mitteilung des DIBt: Fristen für Prüfprogramme von Lüftungsgeräten." 2018. News release. 03.2018, Accessed June 01, 2018. https://www.dibt.de/de/Fachbereiche/data/Fristen_Pruefprogramme_Lueftungsgeraete.pdf.

Passivhaus Institut. 2009. “Anforderungen und Prüfverfahren zur energetischen und schalltechnischen Beurteilung von Passivhaus-Lüftungsgeräten < 600 m3/h für die Zertifizierung als „Passivhaus geeignete Komponente".” http://www.passiv.de/downloads/03_pruefverfahren_l_kleine_geraete_de.pdf, Accessed September 04, 2017.

DIN 1946-6 Entwurf:2018-01 - *Raumlufttechnik – Teil 6: Lüftung von Wohnungen – Allgemeine Anforderungen, Anforderungen an die Auslegung, Ausführung, Inbetriebnahme und Übergabe sowie Instandhaltung*, ICS 91.140.30. Berlin: Beuth Verlag GmbH.

Rietschel, Hermann, and Klaus Fitzner, eds. 2008 - *Raumklimatechnik: Band 2: Raumluft- und Raumkühltechnik.* 16., völlig überarbeitete und erweiterte Aufl. Berlin: Springer-Verlag GmbH, Accessed March 27, 2018. http://fhgonline.fhg.de/bibliotheken/ise/978-3-540-57011-0.pdf.

ANSI/ASHRAE Standard 55:2004-01 - *Thermal Environmental Conditions for Human Occupancy.* Atlanta: ASHRAE.

DIN EN 308:1997-06 - *Wärmeaustauscher - Prüfverfahren zur Bestimmung der Leistungskriterien von Luft/Luft- und Luft/Abgas-Wärmerückgewinnungsanlagen; Deutsche Fassung EN 308:1997*, ICS 27.060.30. Berlin: Beuth Verlag GmbH.

DIN 4108-2:2013-02 - *Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 2: Mindestanforderungen an den Wärmeschutz*, ICS 91.120.10. Berlin: Beuth Verlag GmbH.