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Effect of Bedroom Ventilation on Perceived Sleep Quality in Dutch Houses

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Abstract

Different recent studies have shown that the ventilation of modern Dutch houses, and especially the ventilation of the master bedroom, is often insufficient. Furthermore studies indicate insufficient bedroom ventilation can have a negative impact on sleep quality and next-day performance. The aim of this study was to determine whether the perceived sleep quality was better in Dutch houses with more bedroom ventilation. For this purpose, data from a previous field study, which was focused on the performance of mechanical ventilation systems and its effect on the self-reported health and perceived indoor environmental quality, was reanalyzed. In this previous study the air supply and air exhaust rates of 299 Dutch houses were measured. A questionnaire was used to determine the usage of the ventilation systems by inhabitants and their perceived sleep quality. Statistical analyses were conducted to determine correlations between the amount of ventilation and perceived sleep quality.
In this study significant, but not very strong, correlations were found between ventilation and perceived sleep quality. The results indicate that more ventilation improves perceived sleep quality. Also, there are indications bedroom ventilation may only affect certain aspects of sleep quality.

Keywords – Fresh air supply, MVHR, MEV, inhabitants, GSK

1. Introduction

Different recent studies [1][2] have shown that the ventilation of modern Dutch houses, and especially the ventilation of the bedrooms, is often insufficient. A recent study indicates insufficient bedroom ventilation can have a negative impact on sleep quality and next day performance: Strøm-Tejsen et al [4] found that sleep quality of students improved significantly when the CO_2 level was lower (660-835 vs 2395-2585 ppm). The authors of the same study also concluded that a lower CO_2 level during the night leads to improvement of the ability to concentrate and think logically on the next day. Since the bedroom ventilation of Dutch houses is reported to be

insufficient [1][2], one might expect Dutch inhabitants to perceive a bad sleep quality based on the study of Strøm-Tejsen et al. The central objective of this study was to determine whether the perceived sleep quality was better in Dutch houses (main focuss: the master bedroom) with more bedroom ventilation.

2. Method

Data from a previous field study [1], which was aimed on the performance of mechanical ventilation systems and its effect on the self-reported health and perceived indoor environmental quality, was reanalyzed. In this previous study, among other things, the air supply and air exhaust rates of 299 Dutch houses, built between between June 2006 and January 2008, were measured. Of the 299 houses 150 houses were equipped with balanced mechanical supply and exhaust systems with heat recovery (MVHR) and 149 houses were equipped with mechanical exhaust ventilation systems (MEV) coupled with natural supply through ventilation grilles.

The air supply and air exhaust rates of mechanical ventilation systems were measured with a pressure compensated air volume meter type 'Observator Diff Automatic'. The measurements were repeated for each setting of the ventilation system.

For the natural air supply rate through the ventilation grilles an estimation was made based on the ventilation capacity as reported by the manufacturers of the ventilation grilles. More specifically, the reported ventilation capacity by 1 Pa pressure difference between in- and outside was used.

A questionnaire was used to, among other aspects, determine the usage of the ventilation systems by inhabitants (when do they use which setting of the ventilation system) and their perceived sleep quality. To assess perceived sleep quality inhabitants were shown ten statements regarding sleep quality which were based on a shortened version of the Groningen Sleep Quality Scale (GSK-Scale) [4][5]. Next, for the first 7 statements they were asked to rate on a scale of '1: not applicable at all' to '5: completely applicable' how well the statement described their perceived sleep quality. For the last three statements, the answer categories were reversed: '1: completely applicable' – '5 not applicable at all'. In table 1 the ten statements regarding sleep quality are displayed.

Table 1. Statements of the questionnaire regarding sleep quality and their response scale

Number	Statement	Response scale
1	I often do not sleep at night	1: not applicable at all 2: barely applicable 3: neutral 4: partly applicable 5: completely applicable
2	I often get up at night	
3	I toss and turn a lot at night	
4	I often wake up multiple times at night	
5	I think I often sleep very badly	
6	I feel I only sleep a few hours	
7	I often do not sleep more than five hours	
8	I think I often sleep very good at night	Reversed scale: 1: completely applicable – 5: not applicable at all
9	I often fall asleep easy	
10	I often feel rested when I get up in the morning	

The responses to the ten above statements were combined into the sleep disturbance score (GSK score):

- Respondents who responded to statement 1-7 with 'not at all applicable', 'barely applicable' or 'neutral' scored 0 per statement. Respondents who responded to the same statements with 'partly applicable' or 'completely applicable' scored 1 per statement;
- Respondents who responded to statement 8-10 with 'not at all applicable', 'barely applicable' or 'neutral' scored 1 per statement. Respondents who responded to the same statements with 'partly applicable' or 'completely applicable' scored 0 per statement;
- The sleep disturbance score is the sum of the scores per statements and ranges from 0-10. A sleep disturbance score of 0 means no to little sleep disturbance, a score of 10 indicates a lot of sleep disturbance.

Statistical analyses (Spearman's rank correlation, 2-sided $p < 0,05$) were conducted to determine associations between the amount of ventilation (mainly in the master bedroom) and perceived sleep quality (represented by the GSK-score and the 10 individual sleep quality indicators), separately for each type of ventilation system.

3. Results

In table 2 the measured ventilation rates of the mechanical ventilation systems and the natural air supply capacity of the ventilation grilles are presented. For reference the minimum outdoor air supply requirement from EN 15251 Category III [7] is also shown in table 2.

Dutch residential mechanical ventilation systems normally have 3 settings: high, middle and low. The greatest part of the inhabitants reported to use the

ventilation system on the lowest setting during night (79%). Fourteen percent of the inhabitants uses the middle setting at nighttime, 7% turns the ventilation system off at night and 1% reported to use the ventilation system at the highest setting during night.

Table 2. Measured ventilation rates of the mechanical ventilation systems and estimated air supply capacity of the ventilation grilles.

	Setting ventilation system	MVHR (n=150)			MEV (n=149)			Ref. EN 15251 Cat. III[1]
		P10 [m^3/h]	Average [m^3/h]	P90 [m^3/h]	P10 [m^3/h]	Average [m^3/h]	P90 [m^3/h]	
Air supply rate master bedroom	High	18	41	65	n.a.[2]	n.a.[2]	n.a.[2]	29
	Nighttime	5	17	32	n.a.[2]	n.a.[2]	n.a.[2]	
Total air supply rate in all bedrooms	Nighttime	15	46	82	n.a.[2]	n.a.[2]	n.a.[2]	
Air supply capacity master bedroom	n.a.[2]	n.a.[3]	n.a.[3]	n.a.[3]	30	69	112	29
Total air supply capacity in all bedrooms	n.a.[2]	n.a.[3]	n.a.[3]	n.a.[3]	104	197	328	
Total air exhaust rate in dwelling	High	64	188	298	68	151	225	
	Nighttime	18	77	134	12	71	101	
Total air exhaust rate bathroom and upstairs toilet	Nighttime	5	30	54	4	28	56	

Please note the following regarding table 2:

- the air supply rate is leading for the amount of air exchange in houses with MVHR systems (supply rate < exhaust rate).
- the air exhaust rate is leading for the amount of air exchange in houses with MEV systems (exhaust rate < air supply capacity of ventilation grilles).

[1] According to EN 15251 Category III the required minimum outdoor air supply for an acceptable air quality in existing bedrooms is 14,4 m3/h per person. Often two people sleep in the master bedroom which leads to a reference value of 29 m^3/h for the master bedroom.

[2] n.a.: not applicable for houses with MEV systems since these houses had no mechanical air supply but natural air supply through ventilation grilles.

[3] n.a.: not applicable for houses with MVHR systems since these houses had no ventilation grilles.

In table 3 and 4 the results of the statistical analyses are shown for the dwellings with MVHR systems. In table 5 and 6 the results of the statistical analyses for the dwellings with MEV are shown. Significant correlations (2-sided $p \leq 0,05$) are marked with '*' and are displayed in bold.

Table 3. Correlations between measured ventilation rates in dwellings with **MVHR systems** and the responses of the inhabitants to **sleep quality statement 1-7**.

	Setting ventilation system		I often do not sleep at night	I often get up at night	I toss and turn a lot at night	I often wake up multiple times at night	I think I often sleep very badly	I feel I only sleep a few hours	I often do not sleep more than five hours
Air supply rate master bedroom	High	Corr. Coeff.	-0,11	-0,06	-0,04	0,02	-0,05	-0,02	-0,10
		Sig. (2-tailed)	0,21	0,51	0,66	0,83	0,56	0,80	0,27
		N	127	127	127	127	127	127	128
	Nighttime	Corr. Coeff.	-0,01	0,06	0,03	0,08	0,07	0,06	0,04
		Sig. (2-tailed)	0,95	0,51	0,78	0,40	0,42	0,50	0,69
		N	123	123	123	123	123	123	124
Total air supply rate in all bedrooms	Nighttime	Corr. Coeff.	0,10	0,08	0,01	0,04	0,05	0,02	0,07
		Sig. (2-tailed)	0,28	0,41	0,93	0,69	0,61	0,81	0,41
		N	123	123	123	123	123	123	124
Total air exhaust rate in dwelling	High	Corr. Coeff.	-0,04	-0,12	-0,10	-0,13	-0,06	**-0,18***	-0,11
		Sig. (2-tailed)	0,70	0,16	0,24	0,16	0,52	**0,05**	0,20
		N	127	127	127	127	127	**127**	128
	Nighttime	Corr. Coeff.	0,01	-0,04	-0,06	-0,02	0,04	-0,07	-0,06
		Sig. (2-tailed)	0,93	0,67	0,53	0,86	0,63	0,42	0,53
		N	123	123	123	123	123	123	124
Total air exhaust rate bathroom and upstairs toilet	Nighttime	Corr. Coeff.	0,01	0,04	-0,01	0,02	0,13	0,07	-0,02
		Sig. (2-tailed)	0,87	0,62	0,94	0,84	0,15	0,43	0,87
		N	123	123	123	123	123	123	124

Table 4. Correlations between measured ventilation rates in dwellings with **MVHR systems** and the responses of the inhabitants to **sleep quality statement 8-10 & the sleep disturbance score (GSK).**

	Setting ventilation system		I think I often sleep very good at night	I often fall asleep easy	I often feel rested when I get up in the morning	Sleep disturbance score (GSK)
Air supply rate master bedroom	High	Corr. Coeff.	0,16	**0,27***	0,08	0,09
		Sig. (2-tailed)	0,07	**<0,01**	0,38	0,34
		N	128	**127**	128	124
	Nighttime	Corr. Coeff.	0,11	0,17	0,06	**0,18***
		Sig. (2-tailed)	0,22	0,07	0,51	**0,05**
		N	124	123	124	**120**
Total air supply rate in all bedrooms	Nighttime	Corr. Coeff.	0,09	0,06	0,00	0,18
		Sig. (2-tailed)	0,33	0,48	0,97	0,06
		N	124	123	124	120
Total air exhaust rate in dwelling	High	Corr. Coeff.	0,03	0,07	0,09	-0,06
		Sig. (2-tailed)	0,78	0,46	0,34	0,49
		N	128	127	128	124
	Nighttime	Corr. Coeff.	0,01	0,09	0,10	0,08
		Sig. (2-tailed)	0,87	0,33	0,26	0,41
		N	124	123	124	120
Total air exhaust rate bathroom and upstairs toilet	Nighttime	Corr. Coeff.	0,00	0,07	0,09	0,07
		Sig. (2-tailed)	0,98	0,47	0,31	0,46
		N	124	123	124	120

Table 5. Correlations between measured ventilation rates in dwellings with **MEV systems** and the responses of the inhabitants to **sleep quality statement 1-7**.

	Setting ventilation system		I often do not sleep at night	I often get up at night	I toss and turn a lot at night	I often wake up multiple times at night	I think I often sleep very badly	I feel I only sleep a few hours	I often do not sleep more than five hours
Air supply capacity master bedroom	n.a.[4]	Corr. Coeff.	-0,01	-0,03	-0,09	0,04	0,01	0,04	-0,03
		Sig. (2-tailed)	0,86	0,70	0,30	0,65	0,89	0,68	0,74
		N	142	142	142	142	142	142	142
Total air supply capacity in all bedrooms	n.a.[4]	Corr. Coeff.	-0,11	-0,02	**-,22***	-0,03	-0,02	-0,10	-0,09
		Sig. (2-tailed)	0,18	0,77	**0,01**	0,73	0,77	0,25	0,28
		N	142	142	**142**	142	142	142	142
Total air exhaust rate in dwelling	High	Corr. Coeff.	-0,09	-0,09	-0,16	-0,13	-0,09	-0,11	-0,13
		Sig. (2-tailed)	0,27	0,29	0,06	0,13	0,30	0,19	0,12
		N	142	142	142	142	142	142	142
	Nighttime	Corr. Coeff.	-0,13	-0,05	-0,17	**-,23***	**-,22***	-0,17	-0,17
		Sig. (2-tailed)	0,14	0,58	0,06	**0,01**	**0,01**	0,06	0,06
		N	128	128	128	**128**	**128**	128	128
Total air exhaust rate bathroom and upstairs toilet	Nighttime	Corr. Coeff.	-0,11	-0,02	-0,13	-0,12	-0,16	-0,14	-0,14
		Sig. (2-tailed)	0,22	0,87	0,14	0,16	0,07	0,11	0,13
		N	128	128	128	128	128	128	128

[4] n.a. : not applicable for houses with MEV systems since these houses had no mechanical air supply (only natural air supply through ventilation grilles) and therefore the air supply was not adjustable.

Table 6. Correlations between measured ventilation rates in dwellings with **MEV systems** and the responses of the inhabitants to **sleep quality statement 8-10 & the sleep disturbance score (GSK).**

	Setting ventilation system		I think I often sleep very good at night	I often fall asleep easy	I often feel rested when I get up in the morning	Sleep disturbance score (GSK)
Air supply capacity master bedroom	n.a.[5]	Corr. Coeff.	-0,02	-0,01	-0,11	**-,17***
		Sig. (2-tailed)	0,84	0,91	0,18	**0,05**
		N	142	142	142	**142**
Total air supply capacity in all bedrooms	n.a.[5]	Corr. Coeff.	0,04	0,03	0,00	-0,16
		Sig. (2-tailed)	0,67	0,76	1,00	0,06
		N	142	142	142	142
Total air exhaust rate in dwelling	High	Corr. Coeff.	-0,01	-0,02	0,00	**-,21***
		Sig. (2-tailed)	0,94	0,78	0,99	**0,01**
		N	142	142	142	**142**
	Nighttime	Corr. Coeff.	0,10	0,06	-0,02	-0,05
		Sig. (2-tailed)	0,24	0,52	0,82	0,55
		N	128	128	128	128
Total air exhaust rate bathroom and upstairs toilet	Nighttime	Corr. Coeff.	0,09	0,03	-0,06	-0,03
		Sig. (2-tailed)	0,30	0,78	0,48	0,70
		N	128	128	128	128

[5] n.a. : not applicable for houses with MEV systems since these houses had no mechanical air supply (only natural air supply through ventilation grilles) and therefore the air supply was not adjustable.

For houses with a MVHR system, the following significant correlations were found (see table 3 & 4):

- Inhabitants of dwellings with a higher fresh air *supply rate* in the *master* bedroom (ventilation system on nighttime setting) reported lower sleep disturbance (GSK) scores;
- Inhabitants of dwellings with a higher fresh air *supply capacity* in the master bedroom (ventilation system on highest setting) reported to fall asleep more easily. No such correlation was found for the other 9 sleep quality indicators;
- Among inhabitants of dwellings with a higher *total* air *exhaust capacity* (ventilation system on highest setting) were less persons who reported to only sleep a few hours at night. No such correlations were found for the other 9 sleep quality indicators.

The following significant correlations were found for houses with MEV systems (see table 5 & 6):

- Inhabitants of dwellings where the ventilation grilles in the *master* bedroom had a higher air *supply capacity* reported lower sleep disturbance (GSK) scores;
- Inhabitants of dwellings with a higher *total* air *exhaust capacity* (ventilation on highest setting) reported lower sleep disturbance (GSK) scores. However, no significant correlation was found between the total air exhaust rate which was present when the ventilation system was on the *nighttime* setting and sleep disturbance scores. Nor did the total air exhaust rate in de the rooms upstairs (bathroom and 2nd toilet) significantly correlate with the sleep disturbance scores;
- Among inhabitants of dwellings with ventilation grills with a higher air *supply capacity* in *the master* bedroom were less persons who reported to experience a lot of tossing and turning at night. No such correlations were found for the other 9 sleep quality indicators;
- Inhabitants of dwellings with a higher *total* air *exhaust rate* (ventilation system on the nighttime setting) reported less awakenings at night and less nights in which they slept poorly. No such correlations were found for the other 8 sleep quality indicators;

4. Discussion

The results of this study indicate that more bedroom ventilation leads to improved perceived sleep quality. However, the outcome of this study suggests not every aspect of sleep quality is (equally) affected by ventilation / fresh air supply.

This could be caused by one or more of the following reasons:

- Ventilation might indeed only affect certain aspects of sleep quality. While more bedroom ventilation might make falling asleep easier, as was also found by Lan et al [6], it may for instance not have an effect on sleep duration. More research is needed on this subject.
- The ventilation rates in almost all of the investigated houses can be considered as relatively low (see table 2). The lack of well-ventilated bedrooms could mask a positive effect of ventilation on perceived sleep quality.
- Installation noise might be a confounding variable.

The results of this study suggest that the ventilation rate of the ventilation system on its highest setting has an effect on perceived sleep quality. This is probably no causal relationship since the nighttime setting is the lowest instead of the highest setting in most of the houses. However, a ventilation system with a higher ventilation capacity will, in general, produce less noise when providing the same amount of ventilation as a ventilation system with a lower ventilation capacity. Therefore a higher ventilation capacity can lead to lower installation noise in the bedroom and might thereby improve (perceived) sleep quality.

5. Conclusion

In this study significant, but not very strong, correlations were found between ventilation and perceived sleep quality. The results indicate that more ventilation improves perceived sleep quality. Also, there are indications bedroom ventilation may only affect certain aspects of sleep quality. More research on these aspects is needed.

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