Analysis of the influence of ventilation rate on sleep pattern

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SUMMARY
In this paper, the results from a field study on the influence of ventilation rate on the sleep pattern are presented. The testgroup was asked to sleep in their normal sleeping environment (student dorms) in order to cause as little disruption in the normal pattern as possible. For the same reason, actigraphy was used to measure sleep patterns since this is one of the least disturbing measurement techniques available. The student dorms were selected as a location because all rooms are identical and basic conditions are therefore very similar for all the participants in the study. The participants were also asked to fill out a number of questionnaires to determine their general attitude towards sleep and to get an idea of their subjective appreciation of the sleep quality experienced over the test period. The results show only a very small effect of the ventilation rate on the sleep pattern.

IMPLICATIONS

The results presented are among the very few data available for the assessment of bedroom air quality and its effect on the occupants. In conjunction with other and future data, they will allow to develop ventilation criteria and standards that are specific to the residential situation instead of the office work based criteria that dominate the current standards.

KEYWORDS
sleep, actigrapy, field study, ventilation rate, questionnaire

INTRODUCTION

Most of the available ventilation standards today are based on the perceived air quality theorem presented by (Fanger, 1988). The test data on which this theorem is based are done upon entering a polluted room. In these tests, a rather straight forward relation between the pollution load (expressed in olf) and the appreciation of the air quality by the test panel was found. Based on these findings and the evidence that carbon dioxide (CO_2) is a good indicator for metabolic pollution loads in an environment with no open combustion, a correlation between desired indoor air quality and CO_2 was established, eg. in European ventilation standards (CEN, 2004). In a second stage, the influence of the perceived air quality on office work performance (Wargocki et al., 2002), absenteeism or learning (Haverinen-Shaughnessy et al.) was investigated (Seppanen and Fisk, 2004), establishing a correlation that can be used to trade-off the benefits of higher ventilation rates and the energy and investment cost related to it (Wargocki and Djukanovic, 2005). All of these experiments, however, relate to an active environment.

Some exceptions aside, we spend about 1/3 or our life asleep. This amounts to about 70% of the time we spend at home (Glorieux, 2008). During this time, we are in a semi-conscious state and are not engaged in tasks of which the performance can be measured by output. Therefore, the performance indicators referred to above are only valid in a limited part of the net user time as far as residential ventilation is concerned. Most of the available ventilation standards for the residential context are more or less prescriptive and not performance based eg. the Belgian residential ventilation standard (BIN, 1991). These standards are not suitable for system optimization due to the fact that they fix the sizing and layout of the systems to an absolute value, rather than the performance of the system.

In this paper, we present the first results from a field study that was set up in order to acquire data that relate ventilation rates to the sleep pattern of a test subject sleeping under this condition. This information is crucial for the development of purposely designed criteria for residential ventilation.

METHODS

As was mentioned in the introduction, a field study was set up to analyse the effect of ventilation rate the sleep pattern of the test subjects. The field study was set up in the student dorms because all of the rooms in the dorms are identical and therefore the test conditions are very similar for all of the subjects, while the subjects are still tested in their normal sleeping environment. This was preferred over lab conditions since the move to the lab would introduce adaptation effects. The dorms are not fitted with a ventilation system. From the original group of 10 students, 2 were eventually eliminated due to their failure to comply with the basic test conditions, namely sleeping alone and abstaining from alcohol during the test period.

The tests were executed over a period of 1 month. The test period was divided in 2 sub periods of 2 weeks, in which the test subjects were asked to leave the window open at night during one of the sub periods and to close it during the other. This way, 2 separate conditions were measured, one with a high ventilation rate (window open) and one with a low ventilation rate (window closed). Over the course of the whole test period, carbon dioxide levels (CO_2), temperature and relative humidity were measured in each of the subjects' dorm room. This data is used to characterise the sleeping environment of the test subjects. The CO_2 concentration is used as a proxy for the ventilation rate.

The sleep pattern of the subjects is monitored using the actigraphy technique. This technique was selected because of its easy applicability in situ and its low impact on the sleep of the subject compared to poly-somnography, that is the most commonly used and most accurate measurement technique for sleep patterns, while still rendering acceptably accurate results (Blood et al., 1997). Additionally, the technique is relatively cheap, allowing to test a larger group of subjects simultaneously and over a long period. The data, in 60 second epochs collected with the actigraph devices, were analyse with the Sadeth algorithm (de Souza et al., 2003) and are expressed in numerical values by the number of awakenings, the average time awake, sleep onset and sleep efficiency. Sleep efficiency is the ratio of the time asleep to the total time spent in bed, expressed as a percentage. Sleep efficiencies between 80 and 95 % are considered normal.

Next to the physical measurements, the subjects were also asked to complete a number of questionnaires in order to collect information about their attitude towards sleep and about their subjective appreciation of the quality of their sleep during the test period. For this purpose, a number of questionnaire presented by (Billiard, 2003) were translate to Dutch. The 'Morning Questionnaire' was completed upon awaking every morning to characterise the appreciation of the sleep of that night. At the beginning of the test period, the subjects completed the 'Sleep Impairment Index'-questionnaire (Blais et al., 1997), the

‘Horne and Östberg’ (Horne and Östberg, 1976) questionnaire and the ‘Dysfunctional Beliefs and Attitudes about Sleep’ questionnaire (Morin et al., 2007) in order to assess their attitudes towards appreciation of sleep. The ‘Pittsburg Sleep Quality Index’ questionnaire (Buysse et al., 1989) was completed before the start of the measurement, in between the 2 sub periods and at the end of the test period to assess differences in the appreciation of sleep quality and sleep patterns between the 2 test conditions and the ‘Leeds Sleep Evaluation Questionnaire’ (Parrott and Hindmarch, 1980), designed to assess the effect of medication on sleep over a longer period, was completed at the end of the experiment.

RESULTS

In total, data from 168 nights was collected over the course of the experiment. Due to the uneven spread of holydays and individual schedules of the test subjects during the test period, the number of nights in each of the sub-periods for the same subject varies from 5 to 17. The Peak CO_2 concentration in the high ventilation rate case was between 3000 and 4500 ppm above the outdoor concentration (between 0.2 and 0.3 ACH), while it was between 1000 and 2500 ppm (between 0.4 and 1 ACH) above the outdoor concentration for the high ventilation rate. Note that the concentrations achieved under the ‘high’ ventilation rate condition are still unacceptably high under the criteria from the European non-residential ventilation standard (CEN, 2004), however, compared to the normal condition in the dorms (closed window), there is a significant improvement. The room temperature was kept at about 20°C during the whole course of the test period, in accordance with the usual temperature setpoint of the test subjects.

Figure 1. shows the mean measured sleep efficiency of 6 of the test subjects in the two test conditions and the standard deviation of the sleep efficiency of that subject within the same sub-period. For the two remaining test subjects, the actigraphy data are not available for both sub-periods and can therefore not be compared. No significant impact can be reported, although, with the exception of 1 subject, the sleep efficiency increases slightly when the window is closed. Although even less significant, the number of awakenings and its standard deviation, as depicted in figure 2, also seems to tend towards an negative correlation with the ventilation rate. Nevertheless, whilst the first is results in better sleep quality for lower ventilation rates, the latter implies worse sleep quality for that condition. That negative impact, however, is balanced by the fact that average time awake after each awakening is shorter for the low ventilation rate condition (Figure 3).

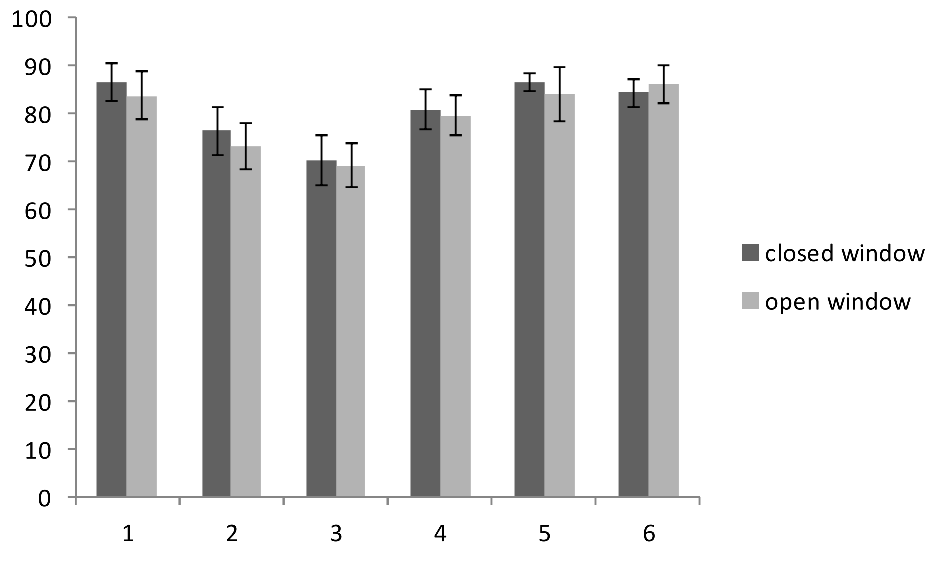

Figure 1. Mean sleep efficiency and standard deviation measured for 6 test subjects over the 2 sub-periods of the test period.

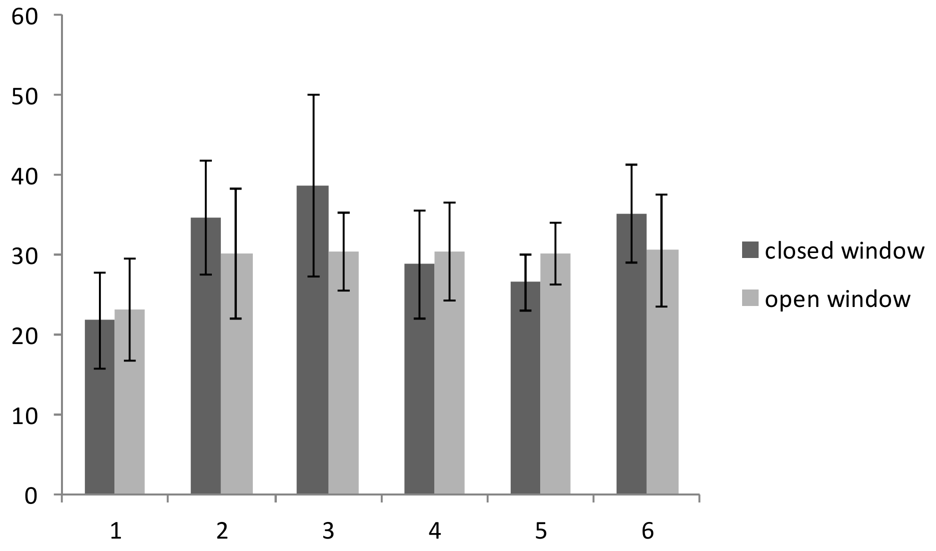

Figure 2. Mean number of awakenings and standard deviation measured for 6 test subjects over the 2 sub-periods of the test period.

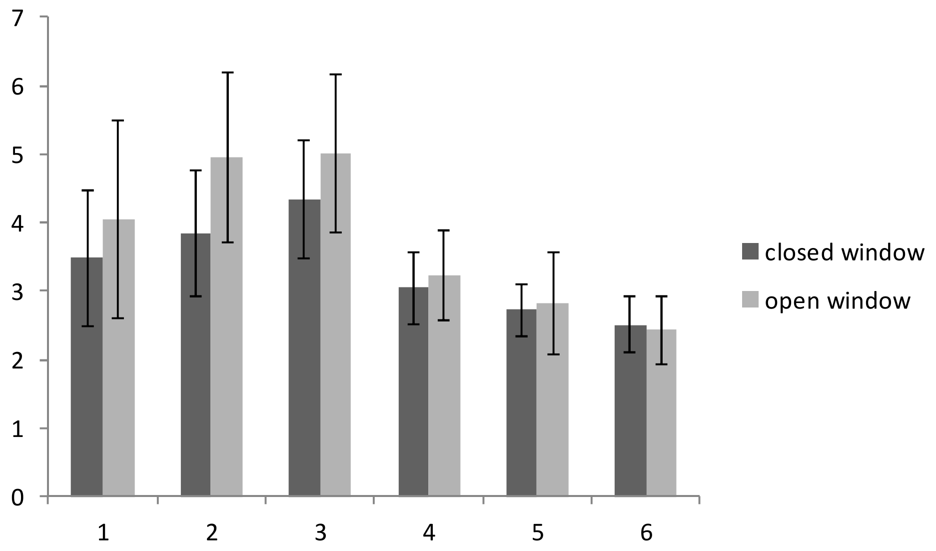

Figure 3. Mean duration of awakening and standard deviation measured for 6 test subjects over the 2 sub-periods of the test period.

If we then look to the questionnaire results, we see that, in contrast to what we see in the actigraphy data, a majority of subjects (6 out of 7) report an increase of the number of awakenings they recall in the morning with an open window. For 1 of the 8 subjects, the questionnaire data is not available for both sub-periods and can therefore not be used to compare both test conditions.

In figure 4 we can see that the test subjects, with 1 exception, reported deeper sleep in the situation with an open window. Additionally, 5 out of 7 subjects reported feeling less rested and less alert upon waking in the morning in the condition with the window closed.

Three subjects report a significant increase in the intensity and amount of dreams in the condition with the window closed, and all of the subjects reported an increase in the number of times they remembered a dream upon waking in the morning.

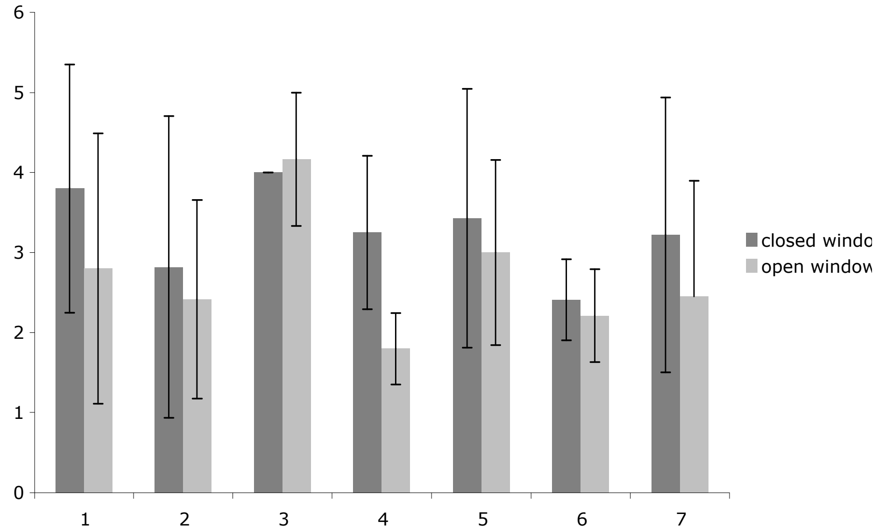

Figure 4. Mean lightness of sleep and standard deviation measured for 7 test subjects over the 2 sub-periods of the test period.

DISCUSSION

The data reported in this paper are a first take at an analysis of the influence of ventilation rates on the sleep pattern of test subjects sleeping under these conditions. They are done on a small test group and in the normal sleep environment of the test subjects. Although this choice is made consciously in order to minimize the impact of the measurements on the sleeping environment, it is not perfectly controlled. Nor, because of the absence of a mechanical ventilation system, again chosen because this is the case in the majority of European houses, could the test be performed with a placebo reference group, since the subjects are aware if the window is opened or not. In order to tackle these constraints, we are now working at repeating the tests to enlarge the test group and comparing the results found in the tests with those from lab experiments. The latter are done under strictly controlled conditions and with full poly-somnography, but, as mentioned above, have a larger impact on the sleeping environment of the test subjects. In the course of next year, the tests will also be repeated in new dorms where mechanical exhaust ventilation is available, again reducing the number of confounding factors. In the results presented here, the confounding effects of the opening of the windows were limited as much as possible and their impact was measured whenever possible. To this end, the participants were asked to report any reasons for awakening and the test was done in autumn to minimize the impact of the opening of the window on the indoor temperature. The measurement data showed equal indoor temperatures in both sub-periods for all subjects and the reported awakening due to noise was not different for the sub-period with the window open since the dorms are situated in a rather quite area. The subjects reported that sound level is mainly dominated by indoor noise such as people coming and going, cooking, bathroom use, showering, elevators... The sound levels associated with these sources were constant over both sub-periods.

CONCLUSIONS

In this paper we reported the results from a field study on the influence of ventilation rates on the sleep pattern of test subjects sleeping under these conditions. The study was designed to monitor the test subjects in their normal sleeping environment. The results showed that the impact of ventilation rates on sleep is complex and diverse. Among the most interesting findings, we see that the test subjects report to be less rested and experience lighter sleep with more dreams under low ventilation rates. The measured sleep efficiency under these conditions was higher, but the number of awakenings during the night increased slightly, the latter is in accordance with the reported lighter sleep.

REFERENCES

Billiard M. 2003 *Sleep physiology, investigations and medicine,* New York, Kluwer Academic.

Bin. 1991. Ventilatievoorzieningen in woongebouwen, Vol. NBN D 50-001, Brussels.

Blais F.C., Gendron L., Mimeault V. and Morin C.M. 1997. Assessment of insomnia: validation of three questionnaires, *Encephale-Revue De Psychiatrie Clinique Biologique Et Therapeutique*, 23, 447-453.

Blood M.L., Sack R.L., Percy D.C. and Pen J.C. 1997. A comparison of sleep detection by wrist actigraphy, behavioral response, and polysomnography, *Sleep*, 20, 388-395.

Buysse D.J., Reynolds C.F., Monk T.H., Berman S.R. and Kupfer D.J. 1989. THE PITTSBURGH SLEEP QUALITY INDEX - A NEW INSTRUMENT FOR PSYCHIATRIC PRACTICE AND RESEARCH, *Psychiatry Research*, 28, 193-213.

Cen. 2004. Ventilation for non-residential builidings - performance requirements for ventilation and room-conditioning systems, Vol. EN 13779, Brussels.

De Souza L., Benedito-Silva A.A., Pires M.L.N., Poyares D., Tufik S. and Calil H.M. 2003. Further validation of actigraphy for sleep studies, *Sleep*, 26, 81-85.

Fanger P.O. 1988. Introduction of the olf and decipol unit to quantify air-pollution perceived by humans indoors and outdoors, *Energy and Buildings*, 12, 1-6.

Glorieux I.M., J. 2008. Belgisch tijdsbudgetonderzoek, Vol. 2010, Brussels.

Haverinen-Shaughnessy U., Moschandreas D.J. and Shaughnessy R.J. Association between Sub-Standard Classroom Ventilation Rates and Students' Academic Achievement, *Indoor Air*, no-no.

Horne J. and Östberg O. 1976. A self-assessment questionnaire to determine morningless-eveningness in human circadian rhythms, *International Journal of Chronobiology*, 4, 97-110.

Morin C.M., Vallieres A. and Ivers H. 2007. Dysfunctional beliefs and attitudes about sleep (DBAS): Validation of a brief version (DBAS-16), *Sleep*, 30, 1547-1554.

Parrott A.C. and Hindmarch I. 1980. THE LEEDS SLEEP EVALUATION QUESTIONNAIRE IN PSYCHOPHARMACOLOGICAL INVESTIGATIONS - A REVIEW, *Psychopharmacology*, 71, 173-179.

Seppanen O.A. and Fisk W.J. 2004. Summary of human responses to ventilation, *Indoor Air*, 14, 102-118.

Wargocki P. and Djukanovic R. 2005. Simulations of the potential revenue from investment in improved indoor air quality in an office building, *ASHRAE Transactions 2005, Vol 111, Pt 2,* 111, 699-711.

Wargocki P., Lagercrantz L., Witterseh T., Sundell J., Wyon D.P. and Fanger P.O. 2002. Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office, *Indoor Air*, 12, 74-80.