Bedroom Indoor Air Comfort: a critical analysis

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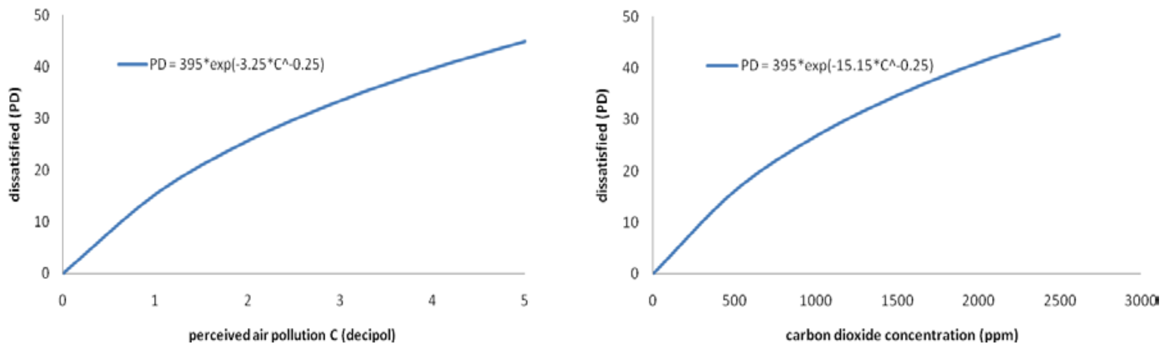
SUMMARY
The criteria that are currently used for the assessment of Indoor Air Quality in a residential context were developed in the '80s and relate to comfort during occupancy. More than half the time at home however, is spent in the bedroom. There is no strong indication that the criteria that are traditionally used to assess Indoor Air Quality also relate to the level of comfort while asleep. Moreover, analysis of the results of a performance assessment of frequently used residential ventilation systems based on these traditional criteria, shows that they are dominated by the pollution level in the bedrooms.

KEYWORDS
Indoor Air Quality, Domestic, Sleep Comfort, Sizing Guidelines

INTRODUCTION
Over the last decades, the depletion of the ozone layer, acid rain and global warming brought new attention to research fields related to environmental care, sustainable development and health. Air pollution is often reported as one of the key elements in many of these phenomena. Additionally, serious efforts have been made to identify the effects of this air pollution on human health and comfort. It is widely recognised that, since most people spend most of their time indoors, indoor air pollution has as much an effect on overall health as outdoor air pollution. Therefore, indoor air quality (IAQ) is a heavily discussed topic within the building physics and indoor environmental quality fields.

In the '80s Fanger (1988) introduced a comprehensive concept to characterise occupant comfort as a function of IAQ by the olf and decipol unit, measure of source strength and concentration respectively. This function predicts the percentage of dissatisfied occupants upon entering the testroom (PD). Figure 1(a) shows the correlation between PD and decipol he found. 1 decipol is the pollution level obtained by a pollutant source of 1 standard person (1 olf) in a room ventilated with 10 l/s of fresh air (Fanger 1988).



(a) (b)

Figure 1. Correlation of pollution level and dissatisfied occupants (a) ifo decipol according to Fanger (1988) and (b) ifo CO_2 concentration above outdoor level (CEN 1998).

He proposes to treat the production of pollutants by the human body of a standard person, caused by metabolic activity, as a unit for source strength. This is especially useful when human activity is the main source of pollution.

Since carbon dioxide (CO_2) is an easily traceable component that is directly related to the human metabolism (in an indoor environment where the human body is the main source of CO_2), it is often used as a proxy for the pollutant level in an occupied space (Seppänen 1999). A classification of IAQ often used in (European) Standards that relates the difference in carbon dioxide concentration between indoor and outdoor environment to the expected percentage of dissatisfied, depicted in table 1 (CEN 2004), is based on these assumptions. The full correlation can be seen in figure 1(b) (CEN 1998). In several recent performance assessments of residential ventilation systems (Vandenbossche 2007, Kornaat 1998), these criteria are used as a basis for the characterization of IAQ.

Table 1. Indoor Air Quality classification ifo CO_2 concentration (ppm) (CEN 2004)

IAQ class	Typical range	Default value
IDA 1	< 400	350
IDA 2	400 - 600	500
IDA 3	600 - 1000	800
IDA 4	> 1000	1200

However, these criteria were developed for occupant comfort. The PD is representative for people upon entering the room, but people tend to adapt fairly quickly to these levels. Additionally, the correlation of nuisance with health effects is not always clear (for a good overview, see Seppänen 2004). Within the residential context, this approach is therefore mainly useful in the living areas.

Occupants, conversely, spend a large amount of the time spent in the house in bed. It is clear that the correlations established with the Fanger method (Fanger 1988) are not representative for this situation, since it is characterized by long consecutive periods of occupancy without direct conscious sensory activity. The average fraction of the time that is spent in the bedroom while being indoors, calculated for 100 reference families in a Belgian reference dwelling developed by the Belgian Building Research Institute (BBRI), is as high as 55%. Figure 2 depicts the average occupancy schedule for these 100 families on a Monday, which also clearly demonstrates the dominance of time spend in the bedroom.

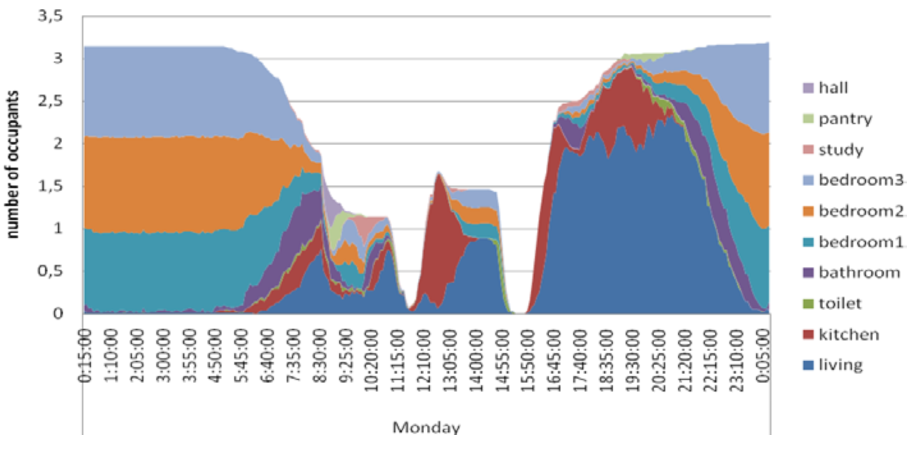


Figure 2. Average occupancy shedule for 100 families in a Belgian reference dwelling

Because of the incompatibility of the traditional criteria and the situation in the bedroom, several relevant questions have to be investigated, such as: What is the response of the human body to longer exposure to higher levels of pollutants, causing nuisance and concentration loss when the occupants are awake, while sleeping? How can IAQ and comfort be characterized when one is asleep?

METHODS

To assess the effect of raised pollution levels on sleep patterns, some research was done on submarines and space missions (eg NASA 1998). The results reported did not demonstrate significant influence of raised CO_2 levels. As was discussed above, CO_2 is only a tracer for a much broader range of pollutants produced by human bio-activity, commonly known as ‘human bio-effluents’. These results can therefore not be considered for this case.

To address the questions raised above, two preliminary actions were undertaken. First, the available information about the performance of standard ventilation systems (Laverge 2009, Vandenbossche 2007) was analysed and used to assess the impact of bedroom concentrations on the overall system performance indicators. The results for a mechanical extraction system with natural supply and a fully natural system are used, as these are the most widely spread systems for residential ventilation in Belgium. The exposure to CO_2 concentrations in the IDA 4 class, as proposed by Vandenbossche (2007), is used as performance indicator.

Secondly a simple first stage experiment was set up to assess effects of variations in pollution level on sleep patterns in a regular residential context. Sleep patterns and sleep quality are commonly measured with polysomnography. This measuring procedure is rather complex and costly. Therefore, it is only used in a medical context. In the context of the problem raised here, it is inconvenient for several reasons. Firstly, it is very complex and has to be carried out by an expert, which makes it inconvenient for the purpose of performing a first experimental assessment. In addition, using available information of measurements in a ‘sleepclinic’ is biased since only people with problems are investigated.

Hence, Actigraphy, a more course but simpler technique (Tvon 1996), is used to carry out a measurement campaign in a normal bedroom. This technique measures the movement of the subject during the sleep period by an accelerometer worn on the wrist. This data is then analysed to identify the different stages of sleep. The activity level of a single test person is evaluated over 2 measurement periods of 1 week each. Ventilation rates are kept to a minimum in the first period and increased in the second period. During the two measurement periods, relative humidity levels (RH), room temperature and CO_2 concentrations are measured to correct for other possible influences.

RESULTS

Sleep analysis

During the first period the average CO_2 concentration reached on average 1500 ppm (1150 above outdoor concentration, IDA 4), during the second period on average 650 ppm (300 above outdoor concentration, IDA 1). Sleep efficiency however, with on average 89 % in the first period and 87% in the second period remained relatively stable.
Some variations were seen in the overall activity level, but these were more than likely caused by a variation in noise level in the room. This will be dealt with in the discussion section of this paper. Furthermore, the test person did not perceive any discomfort during the first week, nor any improvement during the second week.

Impact of bedroom time on current criteria

Both a fully natural and a mechanical extraction system were analysed. The fraction of time above the threshold of 1000 excess ppm that is related to exposure in the bedroom is calculated for these systems. This analysis is done for a range of airtightness levels. As can be seen in figure 3, this fraction is rather large and even equals a 100% for all simulations with the mechanical extraction.

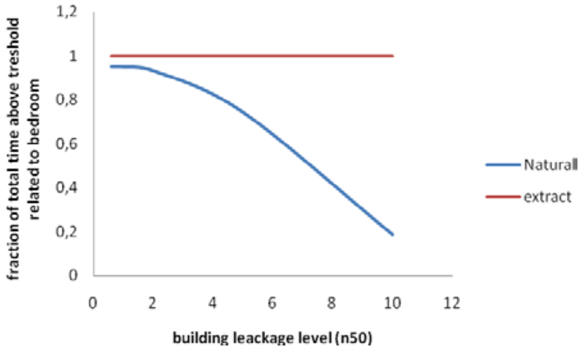


Figure 3. fraction of total time above 1000 excess ppm that is related to exposure bedroom

DISCUSSION

The sleep efficiency measurements discussed above were carried out in a non-airconditionned regular bedroom. Therefore boundary conditions could not be controlled effectively. The raised airflow is achieved by opening a window. This technique has the disadvantage of altering some none measured boundary conditions, especially the noise level. This may have a serious impact on the sleep pattern of the test person. Furthermore, this was a very small scale test. To achieve statistically viable results, a test with a larger test group and better controlled parameters will be carried out in the near future.

CONCLUSIONS

The results presented indicate that currently used criteria for the assessment of IAQ in a residential context do not relate to a consistent methodology for sleep comfort. Since more than half the time at home is spent sleeping, these criteria should be revised. Further research is needed to assess the ventilation rate required for other criteria such as RH, material emissions etc.

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