THE HEALTHY BEDROOM

Authors: Evert Hasselaar[1], Jan van Ginkel[1]
[1]OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology, The Netherlands

Corresponding author: Evert Hasselaar (e.hasselaar@otb.tudelft.nl)

Abstract

We spend one third of our life in a bedroom and hardly question the health issues of the indoor environment. Occupants know little about the ecology of the house dust mite, about how to avoid mould problems, how to ventilate for good indoor air quality.

The bed is likely the main source of house dust mite allergen in the house. Under the sheets air pollutants can reach a 50-fold concentration, compared to the indoor air. Sleeping with two persons in a small bedroom with closed door and no inlet of fresh air causes high moisture and pollutant levels. How healthy is the bedroom?

The research on bedrooms is part of a research project on indicators of healthy housing. One of the results of this project is that indicators have to be selected for each different room in a house and that the bedroom is important because of the long exposure period.

Objective
The objective of the study is to determine the indicators for healthy bedrooms. Indicators that are easy to evaluate by occupants and landlords can support healthy housing and occupant life style that matches the conditions in the house.

Method
Field data were collected in 325 houses, both in houses where occupants complain about maintenance quality, comfort and environmental problems and in reference houses. These data provide insight in occupant behavior and in building related risks and in the relation between occupancy and physical features. For the selection of indicators of house dust mite, 163 dust samples were available. The moisture behavior of mattresses was studied with a mathematical model.

Result
The number of occupants in the dwelling and the type of mattress and bed are useful indicators of the risk level of house dust mite allergen. Maintaining good air quality requires an overflow or exhaust opening and also a free inlet opening in the façade. There is a conflict between heated bedrooms and proper ventilation.

Conclusion
Many bedrooms do not provide a healthy environment during the winter period in moderate and cool climates. The use of ventilation services is low. High occupancy is a good indicator of health risk. Mattresses should be replaced more often, to keep house dust mite allergen levels low.

Introduction

We spend 90% of our time indoors, 50-70% at home and 30% in the bedroom, which is almost one third of our lives. In the bedroom we sleep on soft mattresses, in a single daily time block and housed in secured and solidly walled spaces. This pattern is in contrast with the variety of sleep conditions among traditional peoples, which include multiple and multi-age sleeping partners, frequent presence of animals, with flexible bed- and wake-up times and in exposed sleeping locations that sometimes require fire maintenance and permanent vigilance. We sleep very well secured from the outdoor environment, but is the indoor environment secure, safe and healthy?

During the night, our bodies take a rest from the physical and psychic stresses of the day, we digest and emit metabolic waste and go through many other processes that are essential for long-term health. A healthy bedroom is one that allows us to rest free from environmental stresses. We have the perception that if the vital processes of the body get interrupted all the time, the body and the immune system may slowly worn down and make us vulnerable to disease. Undisturbed relaxation is the basis for health and vitality, two of the most important aspects of the quality of life. As we do complain about lack of sleep and sleep disturbance, does it mean that the bedroom and the bed do not support a period free of stress?

We all care about the environment and healthy housing, but we tend to overlook the bedroom and the bed, probably the most important place in our home. During the day, the body has a highly active regulatory mechanism at its disposal to control the temperature, the ventilation, to remove sources of smell and nuisance. At night, the body, mind and soul are asleep. While asleep, we smell and feel, but we do not act in control of the environment, while the impact of environmental stresses is significant: it affects us but in the morning we tend to walk away from it. Are we neglecting the bedroom?

The healthy housing discipline mainly focuses on the living areas and the kitchen, because of the high occupancy and the hazards and emissions. Will our perception of health risk in houses change, starting from the bedroom?

The paper deals with the following questions:
How do we use the bedroom and what quality criteria our important?
How can we assess the health performance of the bedroom?
What are robust indicators of the health performance of the bedroom?

Problem definition / objectives

The environmental conditions of the occupied bedroom are investigated. The reference is a bedroom in the winter of a moderate climate. The bedroom is for two or more persons, for adults and the elderly or for children. The winter condition is the reference period. The summer allows for windows to be wide open, which means that the indoor climate will resemble outdoor conditions. The winter period brings cold air, so we want to control the smaller ventilation volumes, maybe we start heating the bed or the bedroom.

The indoor environment is being investigated from the viewpoint of the occupants: the physical environment and the users constitute the environment in the occupied bedroom.
The research questions show the need of risk analysis methods. For the purpose of risk assessment, indicators are selected form a large number of phenomena in the bedroom, that have the power to represent these phenomena in a robust way.

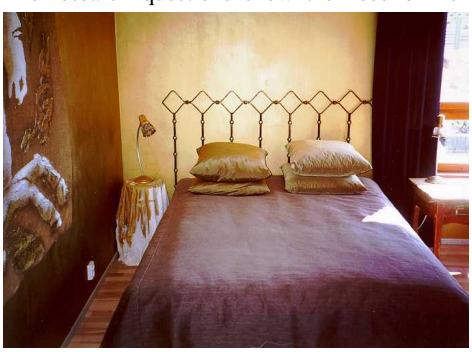


Figure 1. The bedroom for two

Methods

Analysis of a database of 333 houses provided insight in the problems in bedrooms and the relation with the use of heating and ventilation, the type of houses, the construction etc. A total number of 163 dust samples were collected from mattresses of bedrooms, from carpets of bedrooms and living rooms. The allergen

content gave better insight in the meaning of occupancy patterns and for instance moisture levels and the concentration of dust mite allergen. Literature about the ecology has been reviewed, to understand the growth conditions and to build models of the relationship between housing, occupancy and exposure to high allergen levels. The relationships are described in qualitative terms, as the health performance of the bedroom is considered to be the result of complex conditions, defined by building features, interior decoration, occupancy load and user patterns, including cleaning and airing of the bedroom. This paper describes the bedroom as a system, instead of presenting results form specific field data.

Results

The BRE publication 'Building regulation, health and safety' identified twenty seven 'hazards' to health and safety in and around buildings that should be taken into consideration in the formulation of Building Regulations. Those that are of most relevance to the internal environment and the health of occupants have been grouped into ten categories. The information about these categories is adapted from the Housing Health and Safety Rating System (HHSRS) in the UK (Ormandy, 2003):

- Internal temperature and humidity
- Fungi, dust mites and cockroaches, Volatile Organic Compounds
- Contaminants from soil
- Toilets, waste disposal and sewerage
- Noise
- Tobacco smoke and particulates
- Lighting
- Fire
- Falls and other accidents.

User pattern of the bedroom

We focus on bedrooms for two persons. Adults are more active in control of the environment than children, so the master bedroom may present optimal conditions in terms of control. The master bedroom is a useful reference for technical properties and occupants behavior. A bedroom just for sleep gives an exposure period of 6 to 12 hours a day and a combined function with work or hobby or a person who rests in the daytime will increase the exposure time. The surface area and the ceiling height define the air volume of the room and the time it takes for pollutant concentrations to increase. The surface area for the bedroom differs quite much, from 10 m2 and a ceiling height of 240 cm up to 35 m2 and a ceiling height of 260 cm. In social rented houses in The Netherlands we find many master bedrooms with a volume of 35 m3. A general consideration of air volumes to keep concentrations of pollutants caused by humans at a steady level is 25 m3/person.hour, which would require an air change rate of about 1.5 /hour in the bedroom for two adults. That air volume requires quite some effort in terms of ventilation: a very large inlet opening that is not obstructed by curtains, or a large inlet opening plus open door to facilitate cross ventilation, or a door completely open in combination with a bedroom of large volume. In the Netherlands 44% of the master bedrooms receive some heat in the daytime, and 20% of the bedrooms will be heated at night, at relatively low levels. The rest of the bedrooms are not heated during the winter nights. Daytime ventilation of the bedroom will remove absorbed moisture in the mattress, in pillows, bedclothes, wallpaper, flooring etc. Nighttime ventilation determines the pollution peak that will be at the highest level at getup time. Nighttime ventilation is often quite low (air change rate of 0,2 – 0,5) due to fear of draught and cold, due to obstruction of inlet openings by curtains or due to fear of sleep disturbance by noise from outside. According to the dataset, 44% sleep with closed grates or windows in the winter time and for the bedrooms of children this is even higher. In 43% of the houses the door of the bedroom or the connection to other windows does not permit a good flow to exhaust points. As visits in recently built houses show, there is a trend towards sleeping with closed inlet openings (excluding ducted inlet air). Heating the bedroom during sleep increases the use of closed inlet openings with 10% for small inlet openings and 20% for large windows.

Air change rate (ACH) of bedroom (Spangen Rotterdam, 1995)

all closed	*0,1 - 0,3*
inlet grate open, door closed	*0,2 - 0,4*
window and grate closed, door open	*0,3 - 0,5*
window open, door closed	*0,5 - 0,7*
window and door open	*0,7 - >1,2*

In most bedrooms, heavy curtains or blinds (or combinations) are used to block the light, but these curtains block the inlet of fresh air as well. If the inlet grates have a large surface or the window is wide open, a good influx of fresh air will be possible, moved in and out by pressure differences caused by the wind. The cold fresh air will move down behind the curtain and spread over the floor. The warmth of persons in bed causes an up-flow draft of air, which secures the circulation of fresh air near the nose. But the upward flow will not be removed by exhaust openings. There is a circulation of "old air" and the pollutant concentration will rise and can even effect the quality of sleep. The temperature control of the bedroom is a "slave" of the control of the central thermostat in the living room, which means that the temperature tends to be much cooler than in the living room. Many people do not heat the bedrooms at all, or only during periods near and below freezing temperature outside. This means that the temperature differences in the house can be quite large, up to 15 degrees in two different rooms or zones of the house. It can create a flow of vapor from warm to cold rooms and the damp-pressure differences between the wet bathroom and the cold bedrooms may cause mold problems in the bedroom. An important effect of a cold bedroom is that ventilation with high volumes does not cost much energy. This ventilation volume can create a dry indoor environment and low temperatures are not favorable for the house dust mite, whose activity level will slow down below 15 ^{o}C.

House dust mite allergen

The three common species of HDM are Dermatophagoides pteronyssinus, D. farinae and E. maynei. Mite densities tend to be highest in warm humid climates and lowest in cold dry climates, but seasonal variations are important too. The mite is not visible to the naked eye. A mite lives for about two months (depending on species), will lay between 30 and 60 eggs and produce 60 times its size in faecal pellets. Mite feed on protein, provided by human or animal skin particles, preferably material that is of high relative humidity and/or pre-digested by mould. For D. pteronyssinus the protein content of dust must be more than 11% (Koren, 1995). In the home environment, protein-rich food is considered to be abundant in dust, in mattresses, carpets, upholstery and the clothes cabinet. Mites take up water through active extraction from unsaturated air and little through the skin or food. Water is lost as a result of reproduction, defecation and evaporation. The reproduction speed depends on humidity and temperature and the quality of the food, but humidity is the main factor. In population growth experiments at 25 ^{o}C and 70% RH, the mean increase in population size was from 4 (2 pairs) to 1226 +/-131 mites in 126 days (Pretlove, 2001). This indicates the doubling of populations in about 24 days. The reproduction speed depends on temperature, where the period between egg and adult lengthens at lower temperatures (Bronswijk, 1981).

Figure 2. House dust mite

Growth conditions depend mainly on the balance between intake and loss of water. In the home environment this equilibrium can more easily be achieved at relatively low temperatures. One study found that for D. Pteronyssinus the optimal conditions were 25 ^{o}C and 80% RH, but these mites multiplied between 17 ^{o}C and 32 ^{o}C. Above 85% mould toxins will contaminate food supplies. Below the critical equilibrium of around 60-70% RH (different per specie), but in general below 55%, mite will dehydrate and eventually die, depending on the level and period of dehydration. Mite can survive in conditions that are considered hostile, provided there are pockets or regular periods with more favourable conditions. Mite will be killed in frost (dry-frosted).

The World Health Organisation (WHO) suggests a safety threshold of 2 microgram of allergenic protein per gram of house dust. Once above this level the allergen content of the droppings can trigger asthma. If that threshold reaches 10 ug/g of house dust, there is increased risk of severe allergic reactions (Fryer, 2001). The level of allergen Der p1 corresponds with the Acarex test and the guanine level (Koren, 2000). In The Netherlands some medical experts criticize these thresholds: they differ per allergenic person (Ginkel 2004).

Influencing the hygro-thermal conditions at home is considered a possibility for controlling the population of HDM. Also, active removal of old HDM droppings is essential for limiting the exposure. In a research project in 45 houses in North Lanarkshire (Strathclyde, Scotland), half of the number of houses were fitted with mechanical heat recovery ventilation fans, carpets were cleaned and new bedding installed, in order to clear some of the concentration and make the environment drier. Patient's health records were studied over a four-year period and the measures have reduced both general practitioner's consultations and drugs inhaled. Chemical treatment of surfaces is useful, but will not protect for long and many nesting places cannot be cleaned. Washing at high temperatures will kill mites and dissolve faecal pellets, but washing is only possible for smaller items. Chemical cleaning does not remove faecal pellets.

Mattress and house dust mite

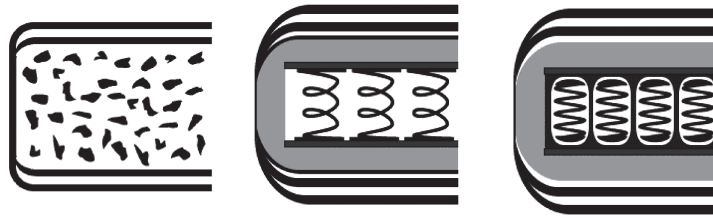
The mattress is the major source of house dust mite allergen in the bedroom. The aerosols deposit on all surfaces. The area under and around the bed has a high concentration of dust from the bed. Part of this dust will become airborne, for instance when someone walks on the floor or when the room is cleaned, while moving around in bed causes emissions of allergic aerosols from the mattress.

A new mattress does not contain mite allergen. When mites infest the new mattress and multiply, it takes some years before the allergen concentration reaches levels that may cause airway irritation. As mattresses grow older, the dust will build up and may reach high levels. Even when the dust mite would stop multiplying after some years, the allergen will stay active in the mattress, only slowly broken down by mould and removed by biological processes. The allergen can stay active for over 10 years. The age of the mattress is an important indicator of house dust mite concentration. Samples taken from mattresses younger than one year do not give a clue about the risk of house dust mite growth. Allergen concentration builds up during summer periods mostly and after two summers the concentration might reach irritable levels, increasing every year.

Very fine woven dust covers prevent live mite to enter the mattress. The covers permit fine dust particles to pass. So when the covers are applied on older mattresses, the effect on the aerosols concentration will be minor. Dust covers should be applied both around the mattress and the pillow and from the moment when new mattresses are used.

The type of bed influences the humidity and the cleaning efficiency. Dust will build up on mattress covers or (without these covers) under the bed on the floor. Without cleaning, the dust layer on the bed-bottom could become the largest source of aerosols. A second effect of the type of bed is the quality of the ventilation in and around the mattress. A bed with springs has much open space and the moisture and aerosols will be vented away. Foam mattresses tend to hold more moisture and create a better habitat for house dust mites.

Figure 3. Foam and spring type mattresses



Heated water beds may have quite moist covers at the end of a sleeping period, as the layer near the plastic cover cannot ventilate. Stains on the plastic refer to transpiration. Permanent heating of the water bed and of using hot wire blankets in the bed give a good protection against mite: the temperature induces evaporation and the mite will not be very active in dry conditions, limiting the activity level and reproduction speed.

Electric hot blanket during daytime:

reduction of mite population between 19 - 85% (de Boer, 1990)

Vacuum cleaning of mattress:

reduction of mite allergen up to 78%

reduction of live mite zero% (Wickman et al. 1997, Allergy)

Chemical treatment:

reduction small and temporarily

Mite protective cover:

reduction of mites, relatively low reduction of allergic dust

Sleeping in exhaled air

Humans act as emission sources of heat, CO2, and moisture from breathing and the body, bio-effluents**.** The amount of CO2 produced is related to the food intake and the activity level of each individual person, but is, compared with activity level typical of office worker, about 200 ml/min. Carbon dioxide levels greater than 800 ppm (1000 ppm) indicate poor air quality. The typical CO2 outdoor concentrations vary between 350 to 575 ppm.

Composition of atmospheric air and expired air in a typical subject. Note that only a fraction of the oxygen inhaled is taken up by the lungs.

Component	Atmospheric Air (%)	Expired Air (%)
N_2 (plus inert gases)	78.62	74.9
O_2	20.85	15.3
CO_2	0.03	3.6
H_2O	0.5	6.2
	100.0%	100.0%

Figure 4. The gases in exhaled air

The ventilation conditions in 35 bedrooms in family houses in La Coruna city (Spain) show, that CO2 levels are much higher than recommended. This was also found in monitored houses in Rotterdam, The Netherlands. The maximum CO2 concentration in the bedroom varied between 2300 and 5480 ppm (Rodriguez,). Values higher than 3000 ppm were reached when the bedroom had the door closed, even when there was only one person. The average infiltration rate varied between 0.66 and 5.04 dm3/s in all cases and was lower than the minimum ventilation rate required for appropriate indoor air quality.

Malcolm describes continuous measurements of the concentration of carbon dioxide (CO2) in inspired air during sleep of 22 children. Carbon dioxide concentrations as high as 2-3% were observed in the prone position when the infant's head was under a blanket and when the lower face was obscured by bedding (Malcolm, 1994).

Potentially dangerous environmental conditions are those where exhaled air is not carried clear of the face by the stream of air issuing from the mouth or nose. Environmental aspects which affect the accumulation of exhaled air at the face include atmospheric pollution, temperature, humidity, bedding arrangement, sleeping position, interaction between the infant and the sleeping environment. Physiological mechanisms can be identified that provide explanation for sudden infant death as a result of prolonged exposure to a hypercarbic atmosphere.

Other pollutants are important too. Conventional mattresses contain many chemicals from glues, foams, pesticides, or chemical flame retardant treatments. Permanent press bedding is treated with formaldehyde that does not wash out of the fabric. Many bedroom materials may be out-gassing for years after we purchase them. As we sleep, we may not only be inhaling these chemicals all night long, but also absorbing them through the skin from our sheets, pillowcases and sleepwear. (H3Environmental, 2000).

What does sleep to our body?

When we sleep, the heat production pattern changes: we get colder hands and feet. This happens while room temperatures tend to get lower during the night. The body regulates the temperature by transpiring, not by widening of veins. This means that a hot bed is inconvenient. Each 1,5 hours we automatically change the position of the body and covers, to stimulate the blood circulation in parts of the body that may suffer from some obstruction. Figure 5 shows how the PM2,5 concentration is influenced by moving around in the bed. The pattern shows periods of deep sleep and of periods with relatively more movements. The aerosols are produced by bed linen and the mattress.

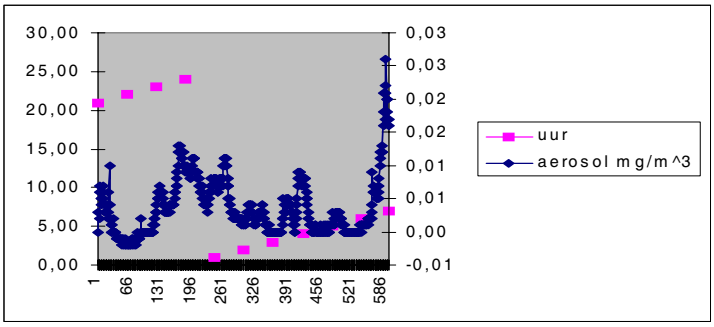


Figure 5. Aerosol concentration (PM2.5) near a sleeping person in bed

Moisture in the bedroom

The moisture production from exhalation and transpiration depends on body mass and temperature and sleep level, but is considered to be 40 g/hour average for an adult person. In an average non-ventilated room and disregarding absorption and condensation, this amount of water would create 100% relative humidity of the bedroom air within one hour. Most water vapor that is emitted during the night is being absorbed in the mattress, in furniture and all surface materials of the bedroom. The amount in the mattress is expected to be 250-300 grams of water. This water diffuses into the mattress due to temperature differences. Our body heat keeps the moisture content high, but the relative humidity low, until we get out of bed. After we get out of bed, the temperature drops to room temperature, creating a high humidity level, that allows the house dust mite to regenerate the water content of its body. After the mattress has dried and better even, after the mattress is cooled down to a temperature below 15 ^{o}C, the house dust mite is not very active, does not eat much, does not reproduce well, while it takes longer for eggs to hatch. A dry environment and low temperatures are considered the best condition to prevent high populations and the associated high allergen levels.

Moisture from skin and breath after a night's sleep:

Skin to mattress and cover = 180-220 g/night.person

Skin to pillow = 15-20 g/night.person

Rough estimate = 250 g each night in mattress

Discussion

Different authors suggest that the quality of sleep is more important than the sleeping period. Night noise exposure, for instance, that disturbs sleep, is a relevant risk factor for stress related diseases. Poor indoor air quality in the bedroom has many influences on health. A low air change rate will increase the radon level, caused by emission from building materials, and create a higher risk of lung cancer: the author's estimate for The Netherlands is that the poor bedroom conditions are responsible for 20% (80-220) radon deaths. Poor ventilation will not remove allergic airborne dust particles (house dust mite and mould) and the high concentration increases the risk of asthma attacks and weakens the conditions of persons with bronchitis and other lung problems: poor bedroom conditions contribute to a great extent to the cause and aggravation of deaths from respiratory problems. The long exposure periods in bedrooms are an important factor for this kind of health risk. The estimate is that 10% of airway related sickness (600 deaths of 6000 a year in The Netherlands) has a direct link with bedroom conditions. Lung conditions weaken in a bedroom with polluted air. The airways of allergic persons have a low resistance to both chemical and biological pollutants, meaning that they are more susceptible to toxic substances and even bacteria. The toxic substances are dangerous for unborn and newborn babies, creating a much higher risk of asthma in children until the age of 12 months (Lehmann, 2004). The estimated excess deaths by inflammation of the lungs are at 5% (275 of 5700 deaths a year in The Netherlands). People get up from their beds during the night, to go to the bathroom. About 500 persons each year have to visit the hospital because of wounds and broken bones from hitting the bed. Because of bad lighting and small bedrooms, hundreds of hospitalizations are caused by falls (Stichting Consument en Veiligheid, 1999). Elderly persons that break a hip, have increased chance of dying within one year.

In The Netherlands the RIVM calculates that 9% of health loss is due to environmental factors and includes accidents. Almost half of this loss (2-5%) is directly related to the physical environment (Staatsen in Kamp, 2003). Looking at the estimates for lung cancer, inflammation of the lungs, respiratory problems and accidents, the rough estimate is that 0,3 – 0,5 % of the total burden of disease in The Netherlands is related to poor bedroom conditions, implicating an extra death toll of 400-700 a year. Better ventilation systems and use of the available inlet openings, replacement of mattresses each 10 years (but 5 years would be better), regular cleaning, removal of emission sources, higher beds and automatic floor lighting would resolve this burden.

Conclusions

Ventilation of the bedroom is often insufficient and ineffective. Good indoor air quality for two persons requires an air change rate of more than 1x the volume of the bedroom per hour. Heating is not relevant for preventing the house dust mite, except when heating is combined with sufficient ventilation. Low temperatures are effective in preventing high explosions of the population, but in many well-insulated houses this condition is difficult to sustain, or the climate only allows for this to happen in cold winter periods. The type and age of the mattress are indicators of the accumulation of house dust mite in the mattress. Improvement of the bedroom conditions would resolve up to 0,5% of the total burden of disease.

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