F: Physical responses & physiology;
F.2. Health assessment (incl. Thermal comfort)

THE INFLUENCE OF THE INDOOR ENVIRONMENT ON SLEEP QUALITY

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SUMMARY

A good sleep is essential for human well-being and for a good performance at work or in school. The physical environment, especially the thermal conditions and the indoor air quality, is important for a good sleep. Wake people are influenced by these two parameters in many different ways, so one may suggest that sleeping people are susceptible for disturbances due to a bad physical environment as well. An extensive literature search identified 24 scientific studies in this field, only six of those deal with indoor air quality. Room temperature above thermoneutrality seems to influence sleep quality in the sense that slow-wave sleep, REM-sleep and total sleep time are reduced. The studies about indoor air quality showed no trends to influence sleep quality. As these studies form a rather thin basis for definite correlations much more research is required especially in the field of indoor air quality.

INTRODUCTION

People spend about one third of their life asleep. A good sleep is important for a stable work performance on the next day and for general well-being. Hence, the bedroom environment should promote a healthy sleep and the physical conditions are an important part of the sleep environment. It is known that ambient temperature and air quality influence wake people in different ways, e.g. performance on office work (Lan et al., 2011), learning in schools (Wyon 1969) and interpersonal behaviour (Kolb et al., 2012, Griffitt 1970). Therefore, the conclusion might be drawn that this is also valid for sleeping environments. In this paper, we aim at synthesising the available knowledge and drawing conclusions about the relationship between the physical environment and sleep quality and identifying future research needs.

METHODOLOGY

A literature search was conducted to find all relevant scientific studies that focus on the influence of ambient room temperature and indoor air quality (IAQ) on sleep quality. To do this, databases, conference proceedings and journal articles were searched. Additionally, references from identified studies and reviews were searched by hand for further data. This search identified 41 studies in total. In a next step, studies were checked if they fulfil some criteria necessary for an adequate interpretation. These criteria were defined as follows:

- First, the participants of the studies should sleep at normal times, i.e. during night-time. Some studies made their participants sleep during the day which disturbs the circadian rhythm and may therefore bias the results of sleep quality – these studies had to excluded.
- Second, there had to be at least one objective measure of sleep quality. If there were just questionnaires filled out by the participants about their sleep quality, the study has been excluded.
- Third, subjects had to be healthy and well-rested, i.e. studies with participants that suffer from sleep disorders or sleep deprivation are not further considered.

Applying these criteria on the identified publications, 24 studies remained for interpretation, of which 18 focus on temperature and only a few analyse IAQ.

To evaluate whether the influence of the physical environment is positive or negative, it is firstly necessary to know what defines a good sleep. Sleep is typically differentiated into four sleep stages and an additional REM (rapid eye movement)-phase (Birbaumer and Schmidt, 2006). Especially the stages 3 and 4 are essential for a good recovery and physical restoring, this sleep phase is called slow-wave sleep (SWS). This part is followed by the REM-phase which is important for mental relaxation, memory processing and learning behaviour (Maquet et al., 2000). A good sleep is defined by alternating phases of slow-wave sleep and REM. If REM-phases are reduced during consecutive days, performance on certain tasks will be reduced (Smith,1995). Reduction of sleep in general refers to reduced vigilance and a more negative mood on the next day (Brendel et al., 1990). Figure 1 shows a typical sleeping pattern during one night.

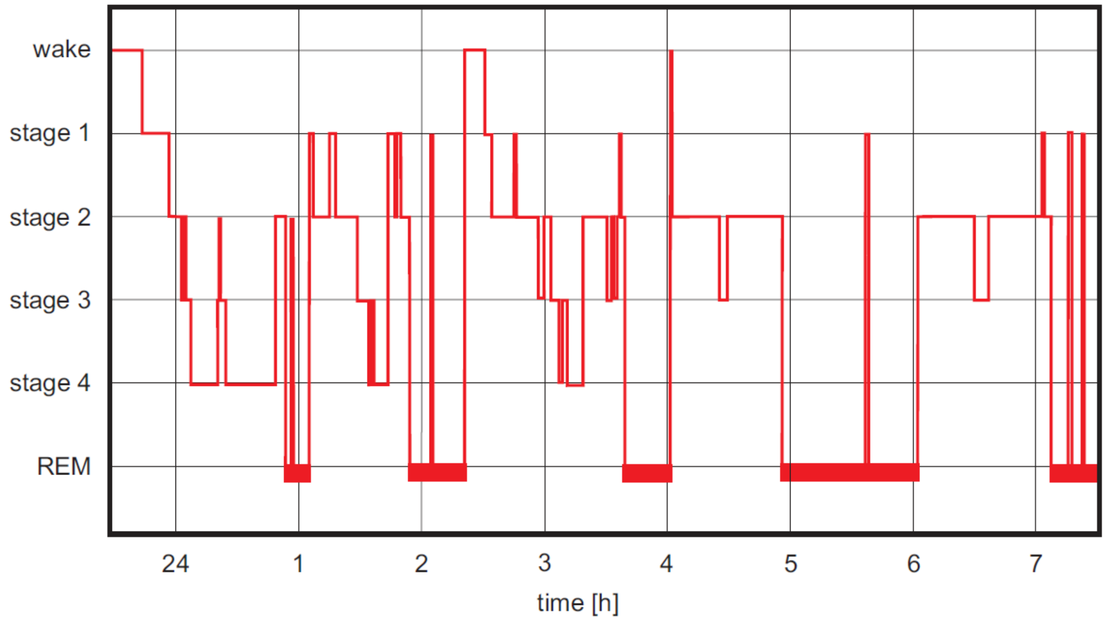

Figure 1. Typical sleeping pattern during one night (Caskardon and Dement, 2011).

RESULTS AND DISCUSSION

Sleep quality and room temperature

To define if a sleep environment induces cold or heat stress to the sleeping person, it is important to consider as well the insulation value provided by the clothing and bed covers in which subjects sleep. In some studies, participants sleep nude and uncovered whereas in others they wear pyjamas and have a quilt.

There are two studies in which cold stress was induced. In Sewitch et al., 1986, six women slept nude and uncovered in a room temperature between 26,7 °C and 28,3 °C. Results showed only, that sleep patterns changed under mild cold stress, e.g. the slow wave sleep increased as well as the latency for the first REM phase, which are both no indicators of a deterioration of sleep quality under these cold conditions. Another study, in which a more severe cold stress (21 °C) was induced to four men sleeping nude and uncovered, showed that cold increases wakefulness (Palca et al., 1986). One study (Haskell et al., 1981a,b) investigated the influence of both cold and warm temperature on the sleep stages. It has been shown that sleep onset latency was shortest in the warmest condition and the greatest disruptions in sleep occurred in the coolest condition. Warm conditions decreased the duration of slow wave sleep (in this specific case by ca. 15 % per a 5 °C increase) and disrupted especially the REM sleep.

Studies that look at sleep quality at slightly beyond thermoneutrality elevated room temperatures (e.g. Lan et al., 2014, Libert et al. 1988, Okamoto-Mizuno et al., 2004) showed that a slightly elevated ambient temperature decreases sleep quality with regards to shorter slow-wave-sleep periods, a decrease of REM-sleep phases and shorter total sleep times.

Some studies compare not only temperature, but also humidity and investigate the influence of hot-humid conditions on sleep quality (e.g. Okamoto-Mizuno et al., 1999, Tsuzuki et al., 2004). Humidity increases thermal load compared to a hot-dry condition due to the limited possibility to sweat. Hence, these studies showed consequently that the hot-humid conditions increased skin temperatures (measure for thermal load) and wakefulness and reduced slow-wave sleep and REM phases.

One further study (Di Nisi et al., 1989) investigates the influence of heat acclimatization on sleep quality at elevated room temperatures. Four subjects were acclimatized over seven consecutive days during the experiment to an operative temperature of 44 °C. Increasing acclimatization showed no effect on sleep quality when sleeping at thermoneutrality. In contrast, when sleeping at an operative temperature of 35 °C, slow wave sleep time increases as this is the sleep phase where thermoregulation is most active. Sweat activity increases as well and leads to a greater amount of body cooling.

Keeping all these results in mind, it seems reasonable to conclude that an inadequate ambient air temperature of the bedroom impairs sleep quality, but, nevertheless, the available data sources are still limited and the conditions in the studies are very different for a sound comparison (e.g. in some studies subjects are heat-acclimatized, in some not, sometimes they sleep nude and without any covering which are not realistic sleeping conditions). Much more research work is needed here in order to be able to systematize the results, to get definite conclusions about the importance of the covering and the acclimatization state and to finally extract correlations wrt. optimal bedroom temperature.

Sleep quality and ventilation

Very few studies could be found for this aspect: only six publications could be identified by the literature search. Two focuses were observable: the influence of ventilation or IAQ in general, i.e. comparing natural ventilation with mechanical ventilation systems, or the use of bedside-personalized ventilation.

It was difficult to find any study that links objective measures of sleep quality with IAQ. There were two studies (Sekhar and Goh, 2011 and Wong and Huang, 2004) that evaluate subjectively the IAQ in bedrooms (but logically when subjects are awake) but deliver no findings how IAQ influences sleep quality. Finally only one study remains that tries to link the IAQ, namely the ventilation rate, in the bedroom (manipulated by window opening or not) to sleep quality (Laverge and Janssens, 2011). Objective sleep measures showed no differences, differences are detectable for the subjective questionnaires about remembered awakenings during the night or the amount of dreams. Numbers of awakenings are higher with open window, the amount of dreams is lower. A weak point of this study is that many variables are not controlled, e.g. with opened windows the noise level may be higher and disturb sleep, and thus the result does not necessarily correlate with IAQ. Consequently conclusions about the influence of ventilation on sleep quality cannot be drawn from this study.

One further study (Laverge and Janssens, 2009) focused on the influence of carbon dioxide (CO_2) on sleep comfort. This was an experiment with one single person sleeping at two different levels of CO_2-concentration (650 and 1500 ppm on average), which were achieved via window opening. Sleep quality was measured by recordings of body movements of the subject and did not change between the different CO_2-conditions. Similarly the retrospective subjective sleep quality did not alter with high or low levels of CO_2-concentration.

Two studies focus on the influence of a bedside personalized ventilation system (Lan et al., 2013 and Zhou et al., 2014). Subjects slept in a thermally-neutral bedroom with or without the personal ventilation system. This ventilation system has an air outlet device directly at the head of the sleeping person so that a zone of clean air is created around the upper part of the bed. Measures of sleep quality showed that elderly persons have a shorter sleep onset latency (Lan et al., 2013) and heart rate variability is reduced (i.e. sleep is deeper and sleep quality is therefore better in the condition with personalized bedside ventilation (Zhou et al., 2014). However, overall the differences reported are not clearly evident.

CONCLUSIONS

Ambient room temperature seems to have an influence on the sleep quality of occupants. Slightly elevated room temperatures decrease the times of deep sleep, indicated by reduced slow wave sleep. REM phases are also reduced and wakefulness increases. Deviations to cold environments show the same pattern. Nevertheless, the different conditions in the experiments are difficult to compare due to the different clothing and covering scenarios and additionally the different humidity patterns (high vs. normal relative humidity). But as sleep is essential for a good next day performance at work or in schools, the promotion of a good bedroom environment has also economic consequences and thus the matter of an optimum thermal environment for good sleep quality should be treated as an important topic in future investigations.

The influence of ventilation on sleep quality is nearly unknown, only one scientific study related to ventilation and one addressing CO_2-concentrations have been found. Both could not identify a significant influence on sleep quality. The influence of a bedside personalized ventilation system which creates a zone of clean air around the head seems to ameliorate some measures of sleep quality in elderly people and to reduce stress and therefore to increase sleep quality. For IAQ, general conclusions cannot be drawn at this stage and more research is necessary to allow the derivation of correlations to sleep quality.

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