Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 205 (2017) 526–532

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Symposium on Heating, Ventilation and Air Conditioning, ISHVAC2017, 19-22 October 2017, Jinan, China

Thermal experience improvement and thermal requirement difference in bed warming conditions

Cong Song*, Yanfeng Liu, Xiaojun Zhou, and Jiaping Liu

School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, 710055, China

Abstract

The human body is exposed to nonuniform thermal environment due to asymmetric bedding coverage of head and covered body. The purpose of the study is to investigate the thermal requirement difference of local body parts during sleep. Experiments were performed both in bed warming and non-bed warming conditions. Twelve healthy postgraduates were recruited as subjects. The thermal states on different local body parts of subjects were obtained via objective measurement and subjective questionnaires. The results showed that thermal comfort during sleep in winter was not in accordance with the thermal neutral state. In order to achieve overall thermal comfort condition, discrepant thermal sensation should be kept be-tween the head and covered body, besides, the disparity in skin temperature was 1.5°C and in TSV was 0.5 between posterior and lateral body part. The study has implications in the energy saving design of the coupled sleeping thermal environment in winter.

Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.

Keywords: Sleeping environment; Thermal requirement difference; Bed climate; Skin temperature

1. Introduction

Cold indoor environment is detrimental to sleep onset and sleep maintenance [1,2]. Bed warming is an effective and energy saving method to moderate the cold-stress stimulation and improve thermal experience in cold weather sleep. In view of the asymmetric bedding coverage of head and covered body, the sleeping thermal environment should be considered as coupled spaces including the indoor thermal environment and the bed climate.

* Corresponding author. Tel.: +86-15102987164.
E-mail address: songcong223@163.com

1877-7058
Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.
10.1016/j.proeng.2017.10.408

Thermal comfort during sleep and sleep quality are closely related to the bed climate as well as to the indoor thermal environment. However, excessive bed warming was reported adverse to sleep maintenance [3,4]. Side effects on improving the thermal comfort level and sleep stability were observed in ambient temperatures between 3°C and 13°C when electric blanket was used before sleep [5,6]. Following problems are that, how does the bed warming method influence thermal experience on the covered sleeping body; whether asymmetry thermal exposure would enhance or undermine the thermal comfort level for sleeping; furthermore, what is the thermal requirement difference between different body parts.

To solve the problems above, experiments were performed based on typical indoor temperatures of non-heating room in Northwest China. Subjects' thermal states including skin temperature and thermal sensation on different local body parts were obtained in both bed warming and non-bed warming thermal conditions. The thermal dissatisfied percentage was regarded as the assessment index for overall thermal comfort.

2. Methods

2.1. Experimental conditions

The experimental study was performed in a room without heating system during a consecutive period of winter between November and December. The experimental thermal conditions covered three indoor operative temperature levels: 8.5°C, 10.2°C and 12.3°C. Besides, the conditions were divided into groups of EB condition (subjects who slept with electric blankets) and NEB condition (subjects who slept without an electric blanket) for each indoor temperature. The thermal resistance of the bedding system including bed, mattress, quilt, and pyjamas was estimated 3.73clo according to previous research [7].

2.2. Measurements

The indoor air temperature and relative humidity were measured by self-recording thermo-hygrometer (Thermo Recorder TR-72ui) with accuracy of ±0.3°C. The temperature of the internal surface was measured via copper-constantan thermocouples which were calibrated be-fore measurement. The bed climate was measured with iButton (DS1923 Hygrochron, Maxim, USA) stitched to the inside surface of the quilts. Besides, subjects' skin temperatures were monitored by iButton (DS1922L) on different body sites. The above parameters were measured throughout the experimental night and recorded with an interval of 10min. The assessment of the sleeping thermal environment was obtained by questionnaires when subjects wake up. The thermal evaluations included thermal sensation on each body parts [8], and the thermal acceptance of the whole body.

2.3. Subjects

Twelve subjects were recruited into the experiment including 6 male and 6 female postgraduates. The subjects were in good physical condition, and their sleep habits were surveyed to ensure a consistent sleep-wake schedule for at least one month before the experiment. Approvals for the study were obtained from each subject; related trainings including understanding of the questionnaires, operation of the experimental devices and items requiring attention was conducted in advance.

2.4. Experimental protocol

Before the experiment, subjects arrived at the room and adapted to the thermal environment for 30 min, followed by a pre-sleep survey about their physical and mental condition during the day. Subsequently, the devices were arranged on subjects' skin surface at specified sites. The subjects went to sleep at 23:00. The next morning, they woke up at 7:00 and completed the morning questionnaire about their thermal state during the sleep period. A pre-test was also conducted before the formal experiment to exclude volunteers for whom the experi-mental environment was unacceptable.