Energy and Buildings 42 (2010) 2044–2048

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Experimental study of human thermal sensation under hypobaric conditions in winter clothes

Haiying Wang [a,*], Songtao Hu [a], Guodan Liu [a], Angui Li [b]

[a] Department of Environment and Municipal Engineering, Qingdao Technological University, Qingdao, China
[b] Department of Environment and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, China

ARTICLE INFO

Article history:
Received 29 March 2010
Received in revised form 21 May 2010
Accepted 20 June 2010

Keywords:
Hypobaric condition
Mean skin temperature
Thermal sensation
Air velocity

ABSTRACT

Hypobaric conditions, with pressures about 20–30% below that at sea level, are often experienced at mountain resorts and plateau areas. The diffusive transfer of water evaporation increases at hypobaric conditions whereas dry heat loss by convection decreases. In order to clarify the effects of barometric on human thermal comfort, experiments are conducted in a decompression chamber where the air parameters were controllable. During experiments, air temperature is set at a constant of 20, air velocity is controlled at <0.1 m/s, 0.2 m/s, 0.25 m/s, and 0.3 m/s by stages. The barometric condition is examined stepwise for 1atm, 0.85 atm and 0.75 atm of simulated hypobaric conditions, which is equivalent to altitude of 0 m, 1300 m, and 2300 m respectively. Ten males and ten females in winter clothes participate in the experiments. Thermal sensations are measured with ASHRAE seven-point rating scales and skin temperatures were tested at each altitude. The main results are as follows: when the altitude rises, (1) the mean thermal sensation drops; (2) people become more sensitive to draught and expect lower air movements; (3) no significant change of mean skin temperature has been found. The results of the present study indicate that hypobaric environment tends to make people feel cooler.

1. Introduction

Among the many possible factors affecting thermal comfort, six are considered the most important: air temperature, radiant temperature, humidity, air velocity, clothes insulation and metabolic rate. Sometimes, atmospheric pressure (AP) is another parameter that should be considered. It has been acknowledged that the diffusive transfer of water evaporation increases at hypobaric conditions whereas dry heat loss by convection decreases [1–3]. Such changes in heat and mass transfer may cause the change of body heat loss and then affect people's thermal comfort feeling. Hideo et al. [4] study the effect of hypobaric conditions on three sedentary male adults, lightly clothed, in warm environment using decompression chamber to simulate different altitude. Their experiments show that as altitude rises, the skin temperatures of face and trunk are higher than those of extremities, and thermal sensations for the face and trunk became warmer, so subjects found it difficult to express their thermal state. This study is performed in warm environment, whether people' thermal sensation would change in cold conditions is not clear.

On the other hand, hypobaric condition goes with hypoxia, which possibly works on human thermoregulatory responses. Thermoregulatory responses in humans exposed to acute hypoxia have been studied extensively with most research focused on thermal perception [5–8] and reaction time [9,10]. Golja et al. [5] investigate the effects of hypoxic exposure on the perception of cutaneous warm and cold stimuli and suggest that sensitivity to cold decreases as a result of exposure to hypoxia. Also Golja et al. [11] study the hypothesis that hypoxia affects the perception of thermal comfort in humans, and indicate moderate hypoxia exposure does not affect the zone of thermal comfort in humans. In the experiments of Golja et al. [5,11] a gas mixture containing 10% O2 in N2 is used to achieve hypoxia instead of hypobaric hypoxia environment. Malanda et al. [8] work over on the cutaneous thresholds for warms and colds under hypoxia conditions of over weighted people and found no significant changes comparing to normoxic conditions. These studies focus on the effect of thermoregulatory responses of hypoxia, not on the contribution of hypobaric exposure on people's whole thermal comfort. Therefore, the present study examines the effects of moderate hypobaric hypoxia on thermal sensation and comfort in terms of human tests.

2. Methodologies

In this study, decompression chamber (4.5 m × 2.5 m × 2.0 m) was used to simulate different altitudes. The highest altitude simulated in experiments was 2300 m. People would not experience altitude sickness when exposed to such altitude.

* Corresponding author.
E-mail address: yingzi75@tom.com (H. Wang).

0378-7788/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2010.06.013

Table 1
Subject characteristics ($n = 20$).

$n = 20$		Mean (SD)	Range
Males	Age (years)	25.2 (1.9)	22–29
	Height (cm)	174 (13.2)	165–184
	Body mass (kg)	67 (7.3)	56–80
Females	Age (years)	23 (1.3)	21–25
	Height (cm)	163 (12.8)	155–172
	Body mass (kg)	52.6 (7.3)	42–60

Twenty healthy subjects (10 females and 10 males) participated in the study. Their characteristics were shown in Table 1. All subjects were healthy, non-smokers. All protocols were approved by the university's ethics committee and conformed to the guidelines contained within the Declaration of Helsinki. Verbal and written informed consent was obtained from each subject prior to the participation of each protocol. Subjects were asked to avoid alcohol, smoking, and intense physical activity at least 12 h prior to each experimental session. All subjects were required to wear winter clothes of underwear, long-sleeved thermal underwear, long-sleeved sweater, trousers, socks and shoes (an estimated clothing insulation value of 1.5 Clo, including the insulation of chair).

The subjects were asked to assess their thermal environment for thermal comfort and draught sensation. Thermal sensation votes were based on the ASHRAE/ISO seven-point thermal sensation scale, which was defined hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (−1), cool (−2) and cold (−3). Draught sensation was scaled as −1, 0, and 1, which represent subject feeling of air movement too high, neutral and air movement too small respectively.

The experiments were conducted in January 2009. The twenty subjects were assigned into five groups, each group comprised of two males and two females. Only one group was tested in the chamber each time. On arrival, subjects entered the chamber sitting for about 20 min. The air temperature in the chamber was kept at 20 °C. The chamber made of thick steel panels was inside an air-conditioned room, see Fig. 1. The temperatures of room and chamber are basically the same. During experiments, the room temperature was kept at 20 ± 1 °C by an air conditioner. The air conditioner was a split type with two indoor units. Inside the chamber, an electric warm air blower with thermostat was used to keep the chamber temperature fluctuating within a narrow range. The air flow induced by the blower was fully dispersed before it approached the subjects. The air velocity in the vicinity of subjects was adjusted by a variable speed fan, which was turned off when the air velocity was kept below 0.1 m/s. An ultrasonic humidifier (YC-B743, Yadu Co. Beijing, China) was used to keep relative humidity inside the chamber at 50 ± 10%.

The time schedule of the experiment was shown in Fig. 2. The subjects were exposed to barometric conditions of 1 atm (0 m), 0.85 atm (1300 m) and 0.75 atm (2300 m) continuously with each barometric condition lasting for 1 h (1 atm = 101.1 kPa). Each decompression process took about 10 min. During the decompression process, vacuum pump was used to suck air from the chamber. When the air pressure dropped to the set value, the vacuum pump was still working, at the same time a pressure balance valve would open to let air flow into the chamber to keep the air pressure constant. So during the experiment, the air in the chamber was exchanged in a rate about 4–6 times/h and would not have problems of air quality. All of the actions were controlled by the decompression controller automatically.

During each barometric condition, air velocity was regulated to <0.1 m/s, 0.2 m/s, 0.25 m/s and 0.3 m/s sequentially every 15 min by one of the subjects. The supply air was sent to a plenum chamber and flowed out through four outlet panels with bore diameter of 10 mm.The subjects were asked to assess their thermal sensation and draught sensation for every velocity condition. Each subject should fill twelve questionnaires during the experi-

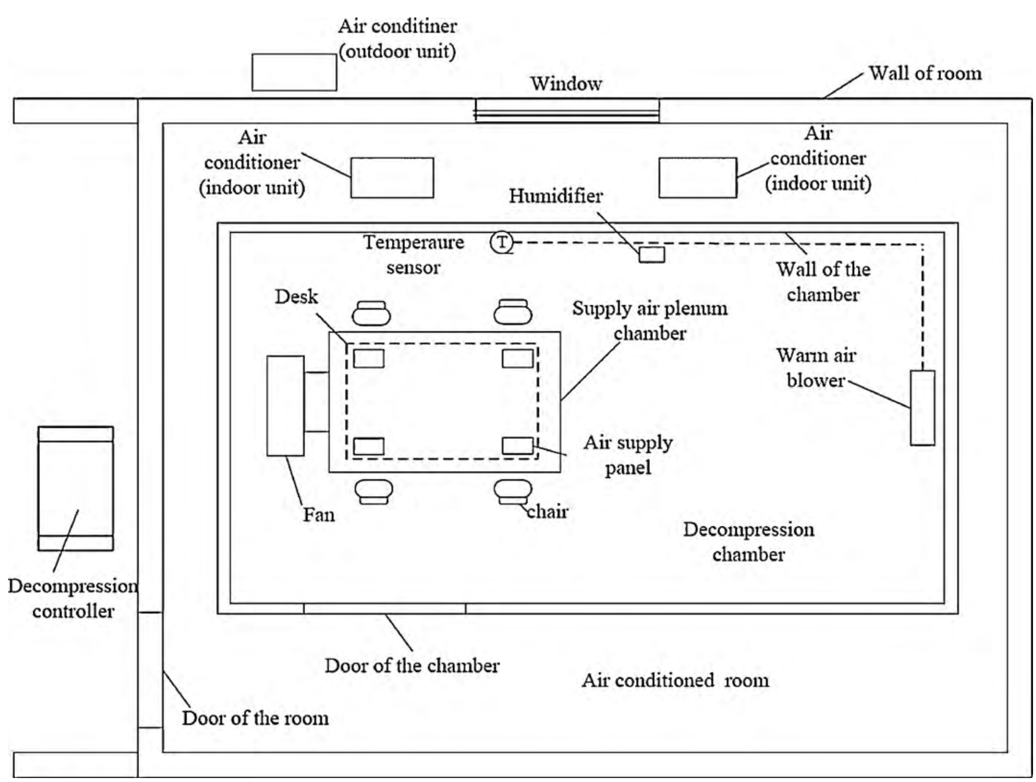

Fig. 1. Layout of the experiment chamber and room.