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Using air movement for comfort during moderate exercise

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ABSTRACT

Fitness centers are energy-intensive in warm climates, cooling the interior to low temperatures that are comfortable for exercise. There is little existing guidance on how to do this efficiently. However it is well-known that significant energy can be saved by cooling sedentary occupants with air movement at elevated setpoint temperatures. This experiment investigated thermal comfort and air movement at elevated activity levels. Comfort votes were obtained from 20 subjects pedaling a bicycle ergometer at 2, 4, and 6 MET exercise intensities in four temperatures (20, 22, 24, 26 °C, RH 50%) under personal controlled ceiling fan airflow, as well as in a 20 °C still-air reference condition. An additional test of frontal airflow was conducted at 26 °C. The hypothesis, that air movement together with higher temperatures would produce equal or better comfort and perceived air quality below the reference condition, was confirmed for every temperature up to 26 °C. Subjects preferred air speeds up to 2.3 m/s to maintain acceptable thermal environment at 6 MET. The small frontal fan affecting the facial area was effective but the ceiling fan affecting the whole body provided greater comfort. Fitness centers should operate with elevated air movement to improve both comfort and efficiency.

1. Introduction

Fitness centers are becoming very popular as people acknowledge exercise to be an essential part of a healthy lifestyle. In United States (US) alone, there are 165,300 fitness centers (including gyms, health clubs, YMCAs and community centers) with 52.9 million members, which in 2013 generated a total revenue of 78.2 billion US dollars [1]. Because of their prevalence and importance, it is prudent to develop heating and cooling strategies for fitness centers that optimize their comfort and energy efficiency.

For fitness centers, it is important that the members are comfortable during their workout. To date there is no comfort standard addressing fitness centers. The most important international comfort standards, such as ASHRAE 55 [2] and ISO 7730 [3] are mainly applicable to sedentary activity as in offices. In the absence of comfort standards for sports facilities, the American College of Sports Medicine (ACSM) [4] recommends maintaining air temperature in all physical activity spaces between 20 and 22 °C, with relative humidity levels lower than 60%. The International Fitness Association (IFA) [5] developed more explicit directions using ranges recommended by both the Occupational Safety and Health Administration (OSHA) and the ACSM. The IFA recommends that those gyms that provide aerobics, weight training, cardio, and Pilates should have an average temperature of 18–20 °C. Both the ACSM and IFA temperatures are far lower than the summer comfort temperatures that are recommended in the ASHRAE and ISO standards for offices. They result in high cooling energy demand in warm seasons, and potential discomfort for those at lower levels of exercise, such as facilities staff who will have different comfort requirements since they are not exercising.

Metabolic rate (met) is the least researched parameter among the six main variables of thermal comfort (the other parameters are dry bulb temperature, relative humidity, mean radiant temperature, air velocity, and clothing level). At high metabolic rates a person's neutral temperature is lower due to the greater heat being generated within the body. McNall et al. [6] tested human subjects dressed in 0.6 clo with three metabolic rate conditions (1.7, 2.2, 2.8 met) at temperatures from 12 to 26 °C, finding neutral temperatures of 22, 19 and 16 °C respectively. In addition, there may be a

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different conception of comfort operating at high rates than at lower rates. Nielsen et al. [7] noted that skin temperatures and sweat rates preferred for comfort depend upon activity level. McIntyre [8] also noted that comfort during exercise is achieved at an air temperature that produces a skin temperature below the sedentary level of about 34 °C but not low enough to suppress sweating.

There are very few studies of air movement and thermal comfort at above–sedentary activity levels. Two studies evaluated the negative effect of air movement – draft risk under higher metabolic rates. Toftum and Nielsen [9] investigated the impact of metabolic rate (1.7 and 2.3 met) on draft discomfort for different ambient temperature (11, 14, 17, and 20 °C) and airflow conditions (0.05–0.4 m/s), and found lower dissatisfaction with draft at the higher met levels. Griefahn et al. [10] investigated differences in thermal comfort, thermal sensation and air movement perception between males and females for varying metabolic rate conditions including 104, 128, 156 W/m^2 (1.8, 2.2, 2.7 met), also finding less dissatisfaction with draft at high activity levels. These studies showed that at higher activity levels, air movement is perceived as pleasant when the body is warm rather than cool.

Jones et al. [11] explored the positive aspect of air movement on improving comfort at higher activity levels. It appears to be the only study specifically designed to have done this. Four subjects dressed in 0.65 and 1.09 clo insulation stepped over two nine-inch steps (2.3 met) under 0.20 m/s air speed at 13–23 °C, and under 1.22 m/s air speed at 16–26 °C. The research found that thermal satisfaction with elevated air speed was equal to or greater at warmer temperatures than those without it at cooler temperatures. The maximum comfort at the elevated air speeds occurred approximately 5.6 °C higher than in the tests without air motion.

Overall, data involving human response to air movement at higher levels of activity is very limited. The objectives of this study were to evaluate whether air movement could provide comfort at temperatures warmer than 20 °C during moderate exercise, and to determine subjects' preferred air speeds under different combinations of temperature and activity levels. The findings were to be useful specifically in fitness center design.

2. Methods

The experiments were conducted at the climate-controlled chamber at the Center for the Built Environment (CBE) in autumn 2014. Twenty human subjects participated in the experiment, with six visits each, during which their thermal responses were recorded under six ambient temperatures and three exercise intensities.

2.1. Facilities and measurement

The test climate chamber measures 5.5 m × 5.5 m × 2.5 m. It controls temperature to an accuracy of ±0.5 °C, and RH ±3%. Mean radiant temperature was controlled to be equal to air temperature. The ventilation rate was maintained near 30 L/s per person during the study, higher than the 10 L/s per person requirement for aerobics rooms (ASHRAE 62.1 2004) [12]. The chamber was divided into two separate spaces to allow two subjects to simultaneously ride on bicycle ergometers without interfering with each other's thermal environment. Fig. 1a shows the experimental setup.

Two ceiling fans were installed directly above the ergometers/subjects. Air speeds were measured between the handlebar and seat of the bike at six heights (0.1 m, 0.6 m, 1.1 m, 1.4 m, 1.7 m and 1.9 m) with omnidirectional anemometers (Sensor Inc., Poland, calibrated accuracy 0.02 m/s). The air speeds were measured in the absence of human subjects, before and after the tests. The mean air speeds of the 1.7 m height were chosen to represent the subjects' exposure, representing their average head and chest level when on the ergometers. The air speeds are shown in Table 1.

Air temperature and globe temperature were measured with a TMC1-HD external sensor connected to a data logger (accuracy ±0.25 °C) every 10 min. Relative humidity was sampled every 10 min using HOBO U12 data loggers (accuracy ±2.5%). An Enmetric wireless power meter (accuracy 0.1 W, sampling rate 1 min) recorded the power draw of each fan to monitor the air speeds selected by the subjects. Skin temperature was sampled every 10 s with iButton DS 1923 Hygrochron temperature/humidity data loggers (Maxim Inc., accuracy ±0.50 °C) attached to subjects' skin with medical tape (3M Healthcare, St. Paul, MN, USA) at four locations (chest, lower arm, mid-thigh, and lower leg [13]).

Testing was carried out with stationary cycling ergometers (Monark 818E, Sweden). The activity intensity for each subject was regulated using resistance imposed on the bicycle flywheel. The subjects' oxygen consumption during the tests was estimated using VO_2 measurement taken in separate subsequent tests. Oxygen consumption was converted to metabolic equivalents (MET, one MET representing resting quietly), a standard unit in sports science for quantifying exercise intensity.

The flywheel resistance was determined by the ACSM procedure represented in Eqs. (1)–(3) [14], using a constant pedaling cadence of 50 *rev/min*. The equations require three variables:

1) Resting oxygen consumption. This is approximately 3.5 *ml/kg∗min*.
2) Oxygen cost of unloaded cycling. The oxygen cost of simply moving the flywheel as well as moving the legs at 50–60 *rev/min* is also approximately 3.5 *ml/kg∗min*.
3) External resistance or load placed on the flywheel, approximately 1.8 *ml/kg*min* for each *kg∗m/min*.

$$VO_2\left(\frac{ml}{kg*min}\right) = Target\ MET \times 3.5\left(\frac{ml}{kg*min}\right) \tag{1}$$

$$Work\ Rate\left(\frac{kg*m}{min}\right) = \frac{\left[body\ mass\ (kg) \times VO_2\left(\frac{ml}{kg*min}\right) - 7\left(\frac{ml}{kg*min}\right)\right]}{1.8} \tag{2}$$

$$Resistance(kg) = \frac{Work\ Rate\left(\frac{kg*m}{min}\right)}{D(m) * \frac{Rev}{\min(rpm)}} \tag{3}$$

where: