Title

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USING AIR MOVEMENT FOR COMFORT DURING MODERATE EXERCISE

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Highlights

- Air movement maintains comfort during exercise in warm temperatures
- Comfort expectations under exercise are different from sedentary
- Subjects' preferred air speeds determined for use in fitness centers

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.

Keywords: Physical activity, Metabolic rate, Thermal comfort, Air movement, Energy saving

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

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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 20-22 °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 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 to 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 to 23 °C, and under 1.22 m/s air speed at 16 to 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.

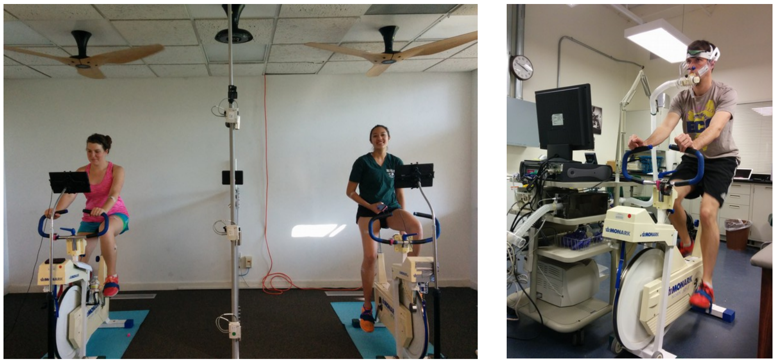
Overall, data involving human response to air movement at higher levels of activity is very limited. The objectives of this study were to evaluate whether air movement could provide comfort at temperatures warmer than 20 °C during moderate exercise, and to determine subjects' preferred air speeds under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



a. chamber setting b. VO_2 measurement

Fig. 1. Experiment set-up and VO_2 measurement

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.

Table 1 Air speeds and power consumption at each speed level

Speed levels	**Air speeds (m/s)**	Power at plug (W)
off	0.05	1.0
1	0.32	2.0
2	0.89	3.0
3	1.05	4.0
4	1.55	6.0
5	2.00	15.0
6	2.30	18.0

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 sec 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 exercise 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 Equations 1 to 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*.

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

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

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

where:

D = distance in meters the flywheel travels with each pedal crank.*

Rev/min = revolutions per minute

* The Monark flywheels move 6m per pedal revolution. (ACSM Handbook)

Based on the equations, 2 MET needs no resistance on the flywheel, while the 4 and 6 MET target workloads are derived from Equation 1 by entering the subjects' weight. It is worth noting that 1 MET is equal to 3.5 ml/kg∗min. Equation 1 uses a fixed value of 3.5 ml/kg∗min for everyone. The research team tested this approximation on three subjects by measuring VO_2 (see Fig. 1b) at Berkeley Sports Physiological Lab, using the same test schedule (See Fig. 3 below) used in the tests. Results showed good agreement between the ACSM prediction and the actual MET values (Fig. 2).

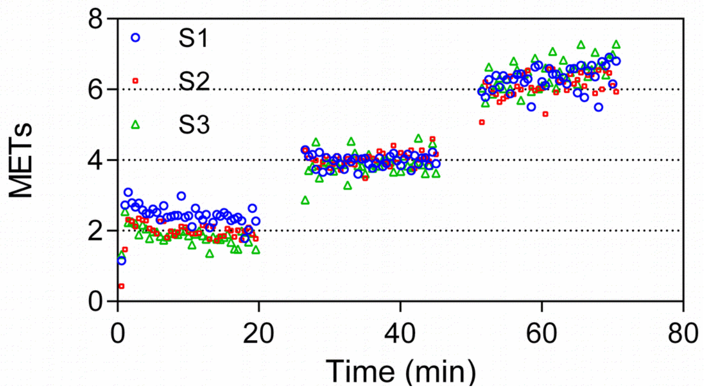


Fig. 2. Validation of ACSM metabolic equation by VO_2 measurements a.

2.2 Test conditions

Table 2 shows the test conditions. It is consisted of four temperatures (20, 22, 24 and 26 °C) at 50% RH with self-controlled air movement from ceiling fans (CF). A separate no-fan (NF) baseline test condition of 20 °C / 50% RH (20NF) was chosen to represent typical fitness center temperature settings (as recommended in ACSM and IFA), where subjects were not allowed to use the fans. In all other conditions, the subjects were given freedom to control the air speed at any moment to one of 7 options: 6 fan speed levels and fan power-off. Before each test session, the subjects were instructed about the fan availability and how to change fan speed with the remote controller. It was not possible to randomize subjects' exposure to temperature conditions because of the thermal time constant of the test chamber.

Table 2 Test conditions

Condition	**Temperature (°C)**	**Fans**	**Exercise intensities (MET)**
Baseline 20NF	20	No fan	2, 4, 6
20CF	20	Fan	
22CF	22	Fan	
24CF	24	Fan	
26CF	26	Fan	

2.3 Subjects

Twenty subjects, mostly university students, participated in all test conditions. They were instructed to dress in typical gym clothes totaling 0.3 clo: tee shirt (or tank top), shorts, sneaker and socks, as visible in Fig. 1a. Before selecting the subjects, background surveys were performed to gather basic information such as height, weight, age, race, weekly exercise, tobacco use, and caffeine consumption. These are summarized in Table 3. The ethnical demographic was 55% White, 25% African American, 10% Asian American, and 5% Hispanic. Three subjects indicated regular exercise for 1-2 hours per week, 12 subjects exercise 2-5 hours, and five subjects exercise more than 5 hours per week. The study was approved by the University of California, Berkeley Committee for the Protection of Human Subjects. All participants provided written informed consent forms before the tests.

Table 3 Subjects' demographic information

	Sample size	Age	Height (cm)	Weight (kg)	**BMI[*](kg/m^2)**
Women	10	23.3±4.7[#]	168.7±6.7	59.8±7.0	21.0±1.7
Men	10	26.0±6.1	176.9±8.0	75.2±9.5	24.0±2.0
all	20	24.7±5.5	172.8±8.3	67.5±11.3	22.5±2.4

[*] Body Mass Index (BMI) = Mass (kg) / Height (m)^2

[#] Standard deviation

2.4 Test procedure

Fig. 3 shows the test procedure used in this study. The subjects were asked to arrive 10 minutes before the test to avoid entering the chamber with an elevated metabolic rate. Before entering the chamber, subjects changed into test clothing and secured the temperature sensors to their skin. In the first 5 minutes inside the chamber, subjects were assigned to their test bikes and were allowed time to prepare for the tests. In the following 20 minutes subjects cycled without resistance while maintaining 50 rpm following the cadence provided by a metronome (2 MET). A 5 min break followed, during which the experimenter changed the ergometer resistance based on the ASCM equation. After the break, subjects cycled at 4 MET while maintaining 50 rpm. The same procedure repeated for 6 MET, followed by a 5 minute cool-down session where subjects were given the option to continue to cycle or rest. The sequence of an increasing MET from start to finish was intended to avoid subjects experiencing higher activity levels prior to lower ones. The persistence of heat or sweat from previous exertion could affect subjects' response to the thermal environment during subsequent lower MET testing.

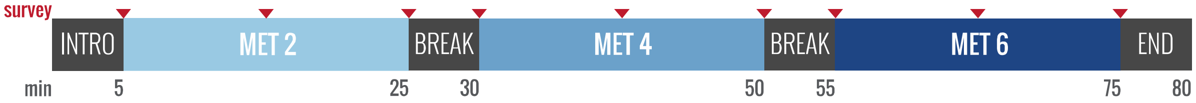
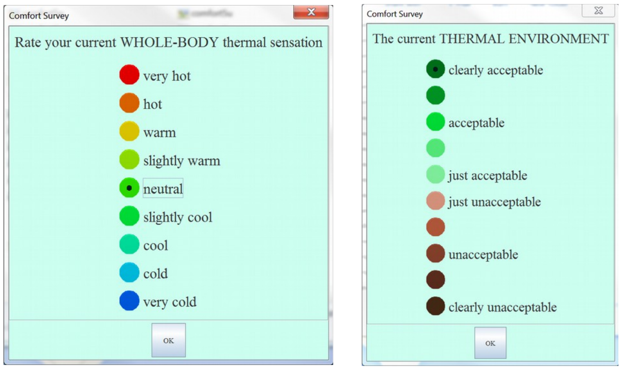


Fig. 3. Test procedure

2.5 Survey questionnaire

Comfort questionnaires (Fig. 4) repeatedly appear on a tablet in front of the ergometers based on the predefined time intervals, to obtain instantaneous thermal sensation, thermal preference and other comfort factors. Discrete survey scales were used because it was difficult for subjects to rate with a slider bar while they were cycling. Subjects rated their thermal sensation (TS), thermal acceptability (TA), air movement acceptability (AMA), and perceived air quality (PAQ) scales responses on radio button scales. The TS scale units are: -4 very cold, -3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, 3 hot, 4 very hot. TA, AMA and PAQ were measured on a ten-point scale with a break, in which the positive values (0.01 'just acceptable' to 4 'clearly acceptable') represent satisfaction and the negative values (-0.01 'just unacceptable' to -4 'clearly unacceptable') represent dissatisfied. Three-point scales are used for thermal preference (TP) (-1 want cooler, 0 no change, 1 want warmer) and air movement preference (AMP) (-1 want less, 0 no change, 1 want more). Surveys were administered electronically every 10 minutes during the 20-min test periods for each MET level (Fig. 3). In addition to the regular thermal comfort questionnaire, the subjects were asked after each exercise level to vote their perceived physical exertion on Borg Rating of Perceived Exertion (RPE) Scale [15].



Rate your current WHOLE-BODY thermal sensation

- ○ very hot
- ○ hot
- ○ warm
- ○ slightly warm
- ● neutral
- ○ slightly cool
- ○ cool
- ○ cold
- ○ very cold

The current THERMAL ENVIRONMENT

- ● clearly acceptable
- ○
- ○ acceptable
- ○
- ○ just acceptable
- ○ just unacceptable
- ○
- ○ unacceptable
- ○
- ○ clearly unacceptable

Fig. 4. Sample survey rating scales

2.6 Frontal fan test

Following the ceiling fan tests, an additional fan was tested at 26 °C (26FF). It was a small fan (15 cm diameter) mounted on the handle bar of the Monark bike, directing an air jet toward the face and the upper body. The goal was to determine whether locally supplied facial airflow would achieve the same effect as a ceiling fan. Eighteen of the 20 subjects (10 men and 8 women) participated in the additional test. The frontal fan air speeds (1.7 m height) were controlled with a variable voltage source to match the mean air speed chosen by the subjects in all the previous ceiling fan tests at 26 °C. The test procedure, questionnaire, measurement equipment were the same as for the ceiling fan tests.

2.7 Statistical analysis

Statistical analysis was performed using Graphpad Prism 6 for Windows (GraphPad Software, San Diego, California US). The experiment was treated as a repeated measures design. The independent variables are fan availability (FAN - no fan, self-controlled ceiling fan, frontal fan), temperature (T- 20, 22, 24, 26 °C), and exercise intensity (MET - 2, 4, 6). Dependent variables are preferred air speeds, skin temperature, thermal and BRE votes. Preferred air speeds were analyzed with a two-way repeated measures analysis of variance (ANOVA) test with temperature, MET and the T-MET interaction as factors. For survey results and skin temperature data, it was decided to treat the data separately for each MET, because the experiment was designed to compare subjective response against the base case of 20 °C instead of qualifying the combined effects of FAN, T, MET and their interactions. Thus data were analyzed with a repeated-measures Friedman test with post-hoc analysis by comparing the self-controlled fan conditions to the base condition, at each MET level. All percentage data (TP, AMP, percentage satisfied (PS)) were analyzed with Fisher's exact test. The same method applied to the analysis of frontal fan versus ceiling fan versus no fan at 26°C. Significance was accepted at 0.05. Data are presented as mean ± CI (95% confidence interval).

3. RESULTS

3.1 Air movement preference and acceptability

Fig. 5 shows the preferred air speeds at each temperature condition. Both temperature and MET have significant effects on the preferred air speeds ($p<0.05$). At 2 MET, subjects preferred very little air movement at 20 °C (0.19 m/s) and 22 °C (0.46 m/s). Preferred air speeds increased to 0.67 m/s at 24 °C, and to 1.19 m/s at 26 °C. At 4 MET the preferred air speeds were 0.38 and 0.70 m/s at 20 °C and 22 °C, increasing to 1.09 and 1.61 m/s for 24 °C and 26 °C, respectively. At 6 MET the preferred air movement was quite high at all temperatures: at 20°C the mean air speed was 1.19 m/s, and at 22, 24 and 26 °C it was 1.66, 1.79 and 1.85 m/s, respectively.

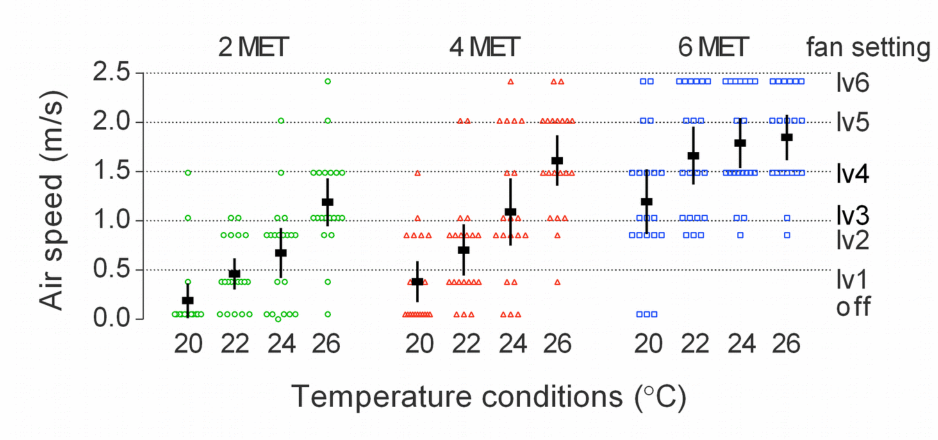


Fig. 5. Preferred air speed at each test condition. Scattered points indicate the individual preferred air speeds; black dots and error bars show the means and confidence intervals (CIs)

Fig. 6a shows the air movement acceptability scale values and the percent of subjects finding air movement acceptable. Votes including and between “just acceptable” (0.01) and “very acceptable” (4) were judged acceptable. No significant difference in acceptability among all temperature conditions was found at 2 MET, but at 4 and 6 MET the fan provided significant improvement in acceptability ($p < 0.05$) over the base condition. At 20NF, the air movement was acceptable to 95% of subjects at 2 MET, 85% at 4 MET, and only 20% at 6 MET. With the fan at 6 MET, the percentage acceptable increased to 75% - 90% at all temperatures.

Fig. 6b shows the air movement preference. Subjects generally preferred no change at 2 MET. At 4 and 6 MET 80% subjects wanted more air movement at 20NF. With personal control over the fan, majority of the subjects preferred no change, however there were still 20-30% of subjects that wanted more air movement, indicating that these subjects might not able to find the right amount of air movement with the 7 fan speed settings.

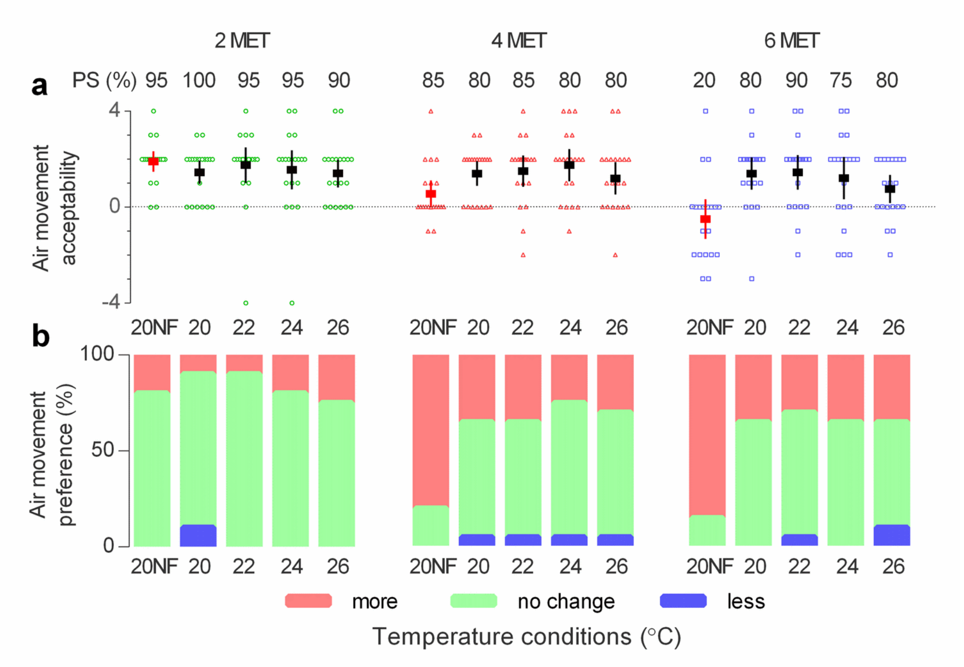


Fig. 6. Air movement acceptability (a) and preference (b). Scatters show the distribution of individual votes. Dots and error bars show means and CIs.

3.2 Thermal responses

Fig. 7a shows the distribution of thermal sensation (TS) votes at each condition. All TS votes at each condition are compared with 20NF base condition. Temperature had a significant impact on TS. At 2 MET, TS votes for all CF conditions were within the neutral range for all temperatures, with no significant differences compared to 20NF. At 4 MET, TS votes for fans were within 'slightly warm' to 'warm' for all the temperatures (20 - 26°C), similar to that of 20NF. The only significant differences were found at 6 MET, where TS votes were generally in the 'warm' to 'hot' range. TS were significantly lower than 20NF at 22CF and 24CF ($p < 0.05$). At 26CF, TS was not different from 20NF.

Fig. 7b shows the percentage of votes regarding temperature preference (TP) for all test conditions. There is a close relation between TP and TS. Subjects generally preferred "no change" at 2 MET while they were thermally neutral, and as their sensation got warmer an increasing number preferred a cooler environment. At 4 and 6 MET with CF, the percentage preferring cooler temperatures was less than that of 20NF, regardless of temperature.

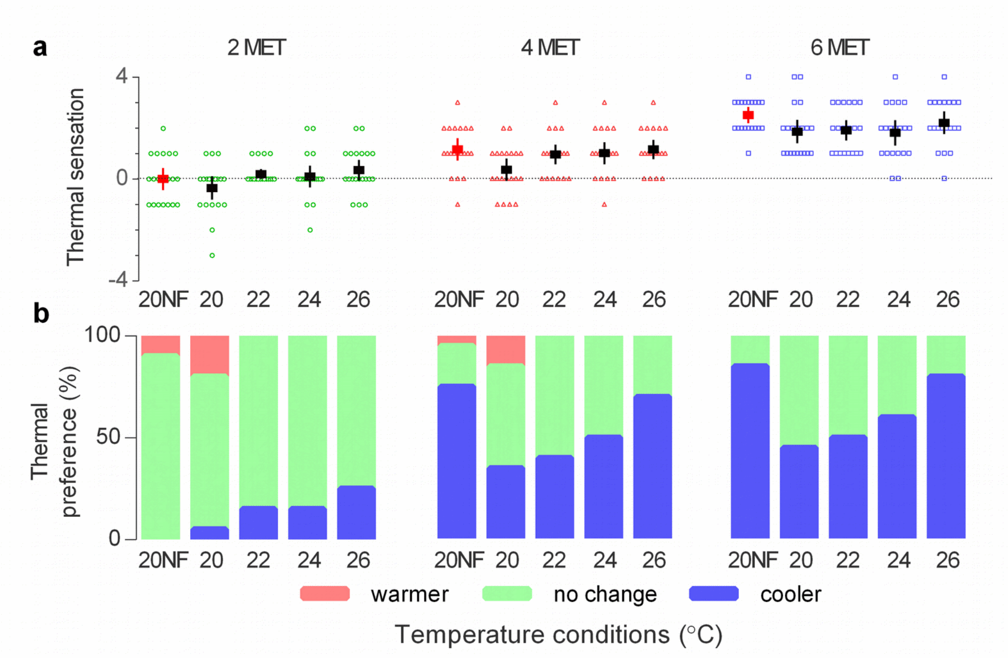


Fig. 7. Thermal sensation votes (a) and thermal preference (b). Scatters show the distribution of individual votes. Dots and error bars show means and CIs.

Fig. 8 shows thermal acceptability (TA) votes for the different conditions, as well as the percent of the subjects (PS) in the acceptable range. At 2 MET, 100% of subjects found the thermal environment of 20NF acceptable. Adding the fan at 20 °C lowered TA because the resulting sensation was slightly cool (Fig. 7a), but at higher temperatures of 22, 24 and 26 °C the TA votes were on the acceptable side with mean values around 2. At 4 MET, no significant differences were found among the conditions. At 6 MET the fan provided significantly higher TA than 20NF ($p < 0.05$) at all temperatures except 26CF, where the increase was not significant. The TA and PS at 26CF were associated with 'warm' to 'hot' TS votes as noted above (Fig. 7a.). Such sensations would produce lower TA values had they been measured under sedentary conditions; this indicates that the relationship between TS and TA is different under exercise conditions.

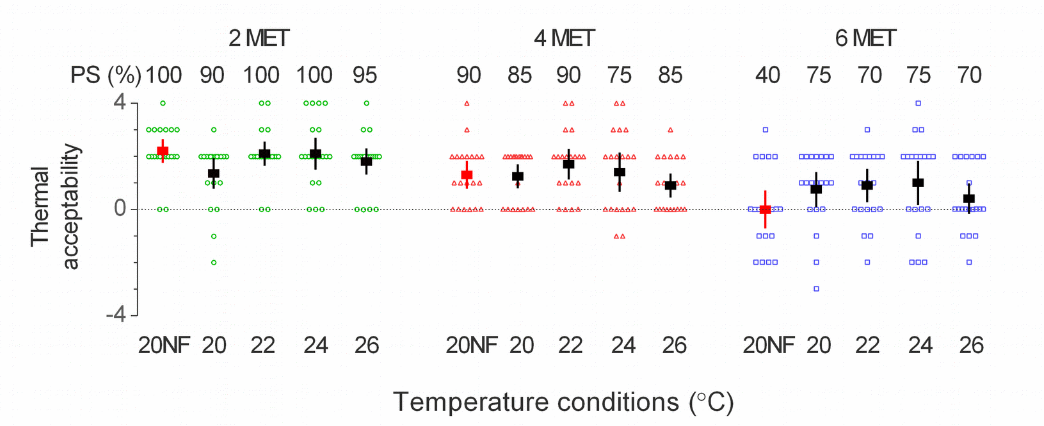


Fig. 8. Thermal acceptability. Scatters show the distribution of individual votes. Dots and error

bars show means and CIs.

3.3 Perceived Air Quality

Fig. 9 shows perceived air quality (PAQ) votes, which closely parallel the TA votes. For 20NF, PAQ decreased significantly as MET increased ($p<0.05$). For MET 2 and 4, temperatures did not have a significant impact on PAQ. At 6 MET, air movement was found to significantly improve PAQ compared to 20NF ($p<0.05$), even at higher temperatures at 26CF. At 2 and 4 MET PS of PAQ were 75% to 100% at all test conditions. At 6 MET PS was improved significantly from 50% 20NF to 80% at all CF conditions.

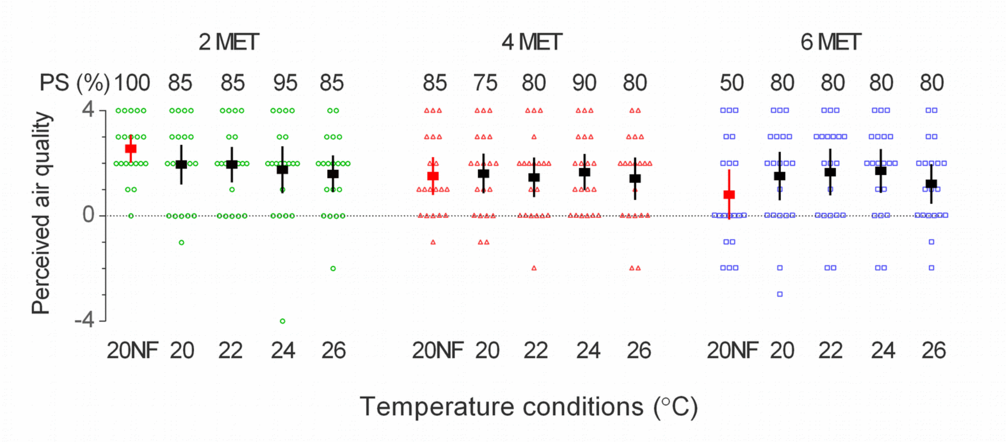


Fig. 9. PAQ votes. Scatters show the distribution of individual votes. Dots and error bars show means and CIs.

3.4 Perceived Exertion

Ideally every subject would have been at the same level of exertion during each controlled exercise. This was not possible because the differences in fitness among test subjects. Fig. 10 shows a large variation in perceived exertion on the Borg scale. Overall, the study's range of temperature conditions produced no significant differences in perceived exertion at each MET level. Subjects' median perceived exertion were respectively 7, 11, 14/15 at 2, 4, 6 MET, corresponding to "extremely light", "light" and "hard" exertion on the Borg scale. The higher the MET level, the bigger the variation among individuals.

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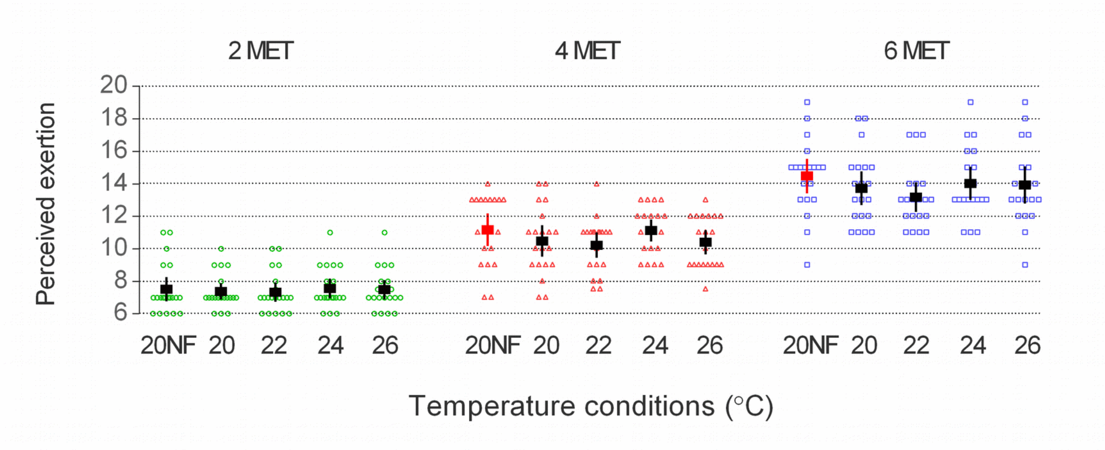

Fig. 10. Perceived exertion on Borg scale. Scatters show the distribution of individual votes. Dots and error bars show means and CIs.

3.5 Skin temperature

Fig. 11 presents the skin temperature at each test condition. Mean skin temperature (T_{sk}) was calculated using the Newburgh and Spealman method [13]. Temperature conditions significantly affected skin temperature at all MET levels ($p < 0.05$). T_{sk} increased with room temperature even though the chosen air speeds increased (Fig. 5) with temperature. At 2 and 4 MET the mean skin temperatures were similar at the same temperature conditions, indicating an insignificant effect of MET on mean skin temperature in these MET ranges. At 6 MET however, mean skin temperature is lower than at 2 and 4 MET at the same room temperature until it reaches 26 °C. This reflects the increased sweating at 6 MET at all temperatures, and the higher chosen air speeds.

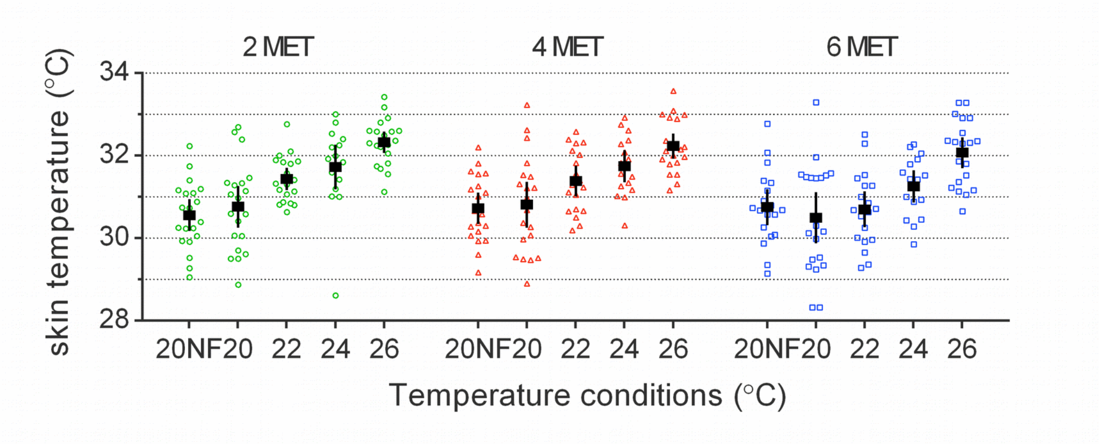

Fig. 11. Skin temperature. Scatters show the distribution of individual votes. Dots and error bars show means and CIs.

3.6 Frontal fan

The frontal fan speeds were determined based on the mean preferred air speeds at 26 °C (at the 1.7m height) in previous self-controlled ceiling fan tests (Fig. 5), which were 1.2, 1.6 and 1.8 m/s for 2, 4 and 6 MET respectively. The frontal fan (26FF) test results are summarized in Table 4 along with the base case (20NF) and the ceiling fan test at 26 °C (26CF). Compared to 20NF, the frontal fan was less effective at 2 MET, but able to maintain the same level of sensation and acceptability at 4 MET and 6 MET. Compared to the 26CF, the frontal fan produced slightly warmer TS, lower TA, and lower AMA. Most of these differences were not significant, with the exception of air movement acceptability at 4 MET. The percentage satisfaction rate, however, was significantly lower for the frontal fan at 4 MET and 6 MET than for the ceiling fan.

Table 4 Summary of results from the frontal fan testing, results shown in Mean (SD) of 18 subjects

	2 MET			**4 MET**			**6 MET**		
	20NF	26CF	26FF	20NF	26CF	26FF	20NF	26CF	26FF
TS	0.2(0.8)	0.3(0.9)	0.6(1.1)	1.1(1.0)	1.1(0.8)	1.5(1.0)	2.4(0.6)	2.2(1.0)	2.2(0.8)
TA	2.2(1.0)	1.8(1.1)	1.2(1.4)*	1.3(1.1)	1.0(1.0)	0.6 (1.6)	0.1(1.5)	0.3(1.2)	-0.2(1.6)
PS	100%	94%	89%	89%	89%	67%	55%	67%	55%
AMA	1.9(1.0)	1.4(1.2)	1.2(1.6)*	0.5(1.2)	1.4(1.3)	0.4(1.6)#	-0.4(1.8)	0.6(1.2)	0.1(1.8)
PAQ	2.5(1.1)	1.8(1.3)	1.4(1.5)*	1.6(1.6)	1.6(1.6)	1.4(1.6)	1.0(2.0)	1.3(1.5)	1.1(1.8)

***Significant difference between 20NF and 26FF, # significant difference between 26CF and 26FF.**
Thermal sensation (TS), Thermal acceptability (TA), Percentage satisfied (PS), Air movement acceptability (AMA), and Perceived air quality (PAQ)

4. DISCUSSION

This study is one of the first to explore the use of air movement for comfort in moderate-to-high activity levels. The results strongly indicate a positive effect of air movement on comfort during exercise. At 20NF baseline condition, acceptability and PAQ decreased significantly at 6 MET, however with personal controlled air movement, acceptability and PAQ were unchanged by MET level even at the high temperature of 26 °C, and significantly better at 22 and 24 °C. The positive effect of air movement on comfort during exercise is due to the increased convective and evaporative heat loss possible with elevated air speeds, offsetting the heat gain caused by exercise. The preferred air speeds found in the current study at different MET levels might therefore be used in future fitness center design. The air speeds are expected to maintain or improve comfort, and to save energy by extending the setpoint deadband in the warm direction [16].

Comparing preferred air speeds of exercising people to the recommended air speed range for sedentary people in ASHRAE Standard 55, exercising people prefer and accept higher air speeds. There is a clear trend that the higher the MET, the preferred air speeds are higher for the same temperature condition. For example, at 20 °C, a low temperature for the clothing worn (0.3 clo), while subjects generally preferred no air movement at 2 MET, they preferred air speeds up to 2.3 m/s at 6 MET exercise. This indicates that the preference and acceptability of air movement depends mainly on people's inner thermal state [17], not on room temperature. Since an exercising person is generally on the warm side of neutral, elevated air movement will restore the thermal stress toward a neutral condition and will therefore be perceived as a pleasant thermal stimulus [18].

The subjects, while controlling air speeds freely, tended to maintain neutral, slightly warm and warm sensations when exercising at 2, 4 and 6 MET respectively. Their acceptability rates remained above 80% despite the warm sensations at 4 MET, and 70% at 6 MET. Furthermore, subjects' skin temperatures were lower than the normal comfortable skin temperature under sedentary state (33 °C). They were also sweating and, though we did not measure this, probably had skin wettedness that in sedentary conditions would be considered uncomfortable. These effects may be expected and considered acceptable by exercising occupants, whereas they would not be accepted by sedentary office workers. This suggests that subjects' expectations about comfort may be different under exercise than under a sedentary state [19]. The reasons might be complex, as Havenith el al. [20] suggested: "In high activity, there may be profuse sweating, blood flow redistribution within the body to supply working muscles, hormonal secretions, and maybe a sense of pleasure, productivity and achievement along with the physical and thermal strain."

Berglund and Cain [21] found that the perception of air quality (freshness, staleness and stuffiness) was independent of metabolic rate, and air was perceived to be fresher and less stuffy with decreasing temperatures from 27 to 20 °C. The current results do not support their findings. Without air movement, PAQ decreased significantly with increased MET even at 20 °C and 50% RH. This may be due to higher rate of bioeffluents generated during exercise and the presence of sweating [22, 23]. With the lack of ambient air speed to disperse the plume of bioeffluents, it is likely the concentration of respired CO_2 and bioeffuents increase with exercise level and cause dissatisfaction with air quality. With elevated air movement, good PAQ was experienced in all test conditions, even at 26 °C and 6 MET. Air movement is an important factor for perceived air quality in exercise conditions, both for cooling the skin and evaporating sweat, and for dispersing the plume of self-polluted air that might otherwise be inhaled.

The small frontal fan was found to maintain acceptable thermal comfort at 26 °C comparable to the base condition, although it was less effective than the ceiling fan at the same temperature. This is mainly because its air movement reaches less body parts than the ceiling fan. Frontal fans with horizontal airflows may be the only option in fitness centers when the ceiling height is too low to install a ceiling fan. In such situations, integrating a fan into stationary bikes or treadmills might be desirable, providing airflow from the front as would be natural for cycling or running outdoors. It is worth noting that in the current study the frontal fan test was only conducted at the warmest temperature of 26 °C. For lower temperatures such as 22 and 24 °C, frontal fans may have the capacity to provide the same level of comfort as ceiling fans. This needs to be explored in future studies. It would also help to increase the fan diameter (eg. a pedestal fan of 25 to 30 cm diameter) over that used in this study (15 cm), so that more of the subjects' body is exposed to airflow.

It has been shown that warm temperatures may increase perception of exertion above that observed in cool and neutral environments at the same exercise intensity [24][25]. However, in this study, perceived exertion was lower at the warmer temperature of 26 °C in the presence of air movement than at the cooler temperature of 20 °C without air movement. Air movement compensated completely for the adverse effect of temperature on perceived exertion, and therefore can improve workout performance in warm environments.

When pedaling on an ergometer, the limb movements of a stationary exercising subject will produce intrinsic air movement over the body, which increases the convective heat transfer coefficient over that of a seated still person [26]. This increase has been quantified as effective air movement (EAM). Nishi and Gagge [27] reported that pedaling on a bicycle ergometer at 50 rpm, the same as in the current study, the overall EAM (in m/s) increased 2 times over that of resting. They also found that the greatest increase in EAM occurs on the thighs and legs, with no significant increase over other body parts. In the current study, we used the 1.7 m height air speed (head, chest level) to represent the air movement experienced by subjects. Thus our upper-body air speed is close to EAM. Heat loss from the upper body is more important in warm temperatures.

There are two approaches to determine activity intensities, one used by sports physiologists and physicians, and another by the building engineering community. Both approaches use the variable MET/met (a multiple of the resting energy expenditure) but they have different underlying bases and are not necessarily equivalent. The ACSM approach normalizes metabolic rate by body mass (3.5 ml/kg$_*$min oxygen uptake equals 1 MET) [28], while the thermal comfort standards for buildings normalize by body surface area [29] (58.2 W/m^2 equals 1 met) where the watts can be determined from oxygen consumption [30]. The two units are based on different standard average persons for whom data is lacking, so they are not easily converted. In order to better integrate physiology and building engineering, it would be useful to develop such a conversion. The current study employed the ACSM method because it is commonly used in exercise training, testing, and exercise prescription, which is important for exercise practitioners to adopt the current findings in the design and operation of fitness centers.

It is worth noting limitations in the current study that might be addressed in the future. The subjects' fitness level, which was not controlled in the current study, may contribute to the variation in preferred air movement and subjective sensations. Gagge et al. [31] and Gonzalez [32] suggested that the relative exercise level may affect people's comfort perception, with more fit people tending to feel more comfortable while doing vigorous exercise. Age and gender may also affect both thermal responses and preferred air movement in exercise. It was not possible here to explore the effects of age and gender difference meaningfully due to relatively small sample size. The current results apply mainly for young, healthy people. Subsequent studies might control for gender, age, also fitness level (eg. controlling subjects to exercise at a same percentage of their maximum VO_2 levels) to better understand the comfort requirements of all populations during exercise.

5. CONCLUSIONS

1. Self-controlled air movement maintains thermal comfort, PAQ and perceived exertion at temperatures of 20 to 26 °C compared to 20 °C without air movement;
2. Subjects' expectation of comfort are different during moderate exercise, they preferred a slightly warm sensation at 4 MET, and a warm sensation at 6 MET, resulting in wider acceptable temperatures in exercise;
3. Subjects accepted and preferred a much wider range of air speeds than is found in the sedentary state; their skin temperature was also cooler while doing exercise than when sedentary;
4. The preferred air speeds at the combination of MET and temperatures could be used to design fan systems in sports facilities, and to allow their operation with energy-efficient elevated setpoint temperatures.
5. Using air speed comfort control in fitness centers can solve the problem of cold discomfort among the non-exercising staff. This is because air speed is inherently localized and able to be focused on the exercising clientele and not on the staff.

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