Association of Ambient Indoor Temperature with Body Mass Index in England

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Objective: Raised ambient temperatures may result in a negative energy balance characterized by decreased food intake and raised energy expenditure. This study tested whether indoor temperatures above the thermoneutral zone for clothed humans (~23°C) were associated with a reduced body mass index (BMI).

Design and Methods: Participants were 100,152 adults (≥16 years) drawn from 13 consecutive annual waves of the nationally representative Health Survey for England (1995-2007).

Results: BMI levels of those residing in air temperatures above 23°C were lower than those living in an ambient temperature of under 19°C ($b = -0.233$, $SE = 0.053$, $P < 0.001$), in analyses that adjusted for participant age, gender, social class, health and the month/year of assessment. Robustness tests showed that high indoor temperatures were associated with reduced BMI levels in winter and non-winter months and early (1995-2000) and later (2001-2007) survey waves. Including additional demographic, environmental, and health behavior variables did not diminish the link between high indoor temperatures and reduced BMI.

Conclusions: Elevated ambient indoor temperatures are associated with low BMI levels. Further research is needed to establish the potential causal nature of this relationship.

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Introduction

The thermal environment has a pervasive influence on energy expenditure and intake in human and nonhuman mammals where an optimal temperature must be maintained consistently. However, whether active thermal regulation and dietary changes in response to enduring thermal exposures have implications for human body weight is currently unclear (1,2). Humans spend much of their time in a relatively homogenous range of "comfortable" ambient temperatures known as the thermoneutral zone (TNZ). This zone is in the region of 20.3–23°C for clothed humans (where the clothing level has an insulating effect equivalent to wearing a business suit) (3,4). The TNZ is associated with reduced metabolic demands as little energy is expended on thermal regulation.

Rigorously controlled laboratory studies have shown that reductions in air temperature from 22°C to 16–17°C produce a graded increase in energy expenditure in clothed humans (5-7). This additional energy is used to maintain thermal homeostasis through acute shivering and the generation of heat in tissues. A broad set of studies of human and nonhuman mammals suggest that the extra energy expended at temperatures below the TNZ may be offset by a compensatory increase in appetite and calorie intake (8,9). This food intake contributes to heat production through an enhanced conversion of calories to heat energy, or the facultative component of diet-induced thermogenesis (10). Thus, there may not be a notable energy imbalance at low ambient temperatures where both energy expenditure and intake are likely to be increased.

In contrast, a negative energy balance and weight loss may occur at temperatures above the TNZ, where heat loss is difficult, requires energy and appetite is suppressed (11-13). High ambient temperatures can affect core body temperature and this can produce a corresponding increase in resting metabolic rate (10–13% per 1°C) (14). To maintain thermal homeostasis energy is expended in heat dissipation (e.g., through evaporative heat loss). This energy expenditure is coupled with decreased food intake as the ingestion of calories would generate excess heat through obligatory diet-induced thermogensesis (1,10). In line with these findings, the nonhuman animal literature indicates that reduced feeding and weight loss occurs at temperatures above the TNZ, even when food is freely available (13,15).

Taken together, prior studies suggest that there may be a crucial energetic divergence at ambient temperatures above the TNZ. Thus, the current study sought to test the hypothesis that those living in homes where the ambient air temperature is above the TNZ (~23°C) will have a lower BMI than those living in colder conditions.

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TABLE 1 **Characteristics of participants from the Health Survey for England (HSfE), divided into the complete sample, high (over 23°C) and other indoor temperature groups, and subsample with additional control variables**

	Full sample (*N* = 100,152)	High temperature (>23°C) sample (*N* = 16,408)	Other temperature groups sample (*N* = 83,744)	Additional controls (*N* = 34,052)
Variables	M (SD) / %	M (SD) / %	M (SD) / %	M (SD) / %
Core study variables:				
Body mass index (kg/m^2)	26.68 (4.76)	26.52 (4.77)	26.71 (4.76)	26.75 (4.89)
Indoor temperature (°C)	20.78 (2.52)	24.64 (1.55)	20.03 (1.91)	20.88 (2.44)
Demographic:				
Age (mean years)	47.56 (17.70)	47.75 (18.04)	47.52 (17.63)	46.34 (17.88)
Female (%)	53.10%	53.63%	53.00%	53.27%
Professional (I)	4.70%	4.56%	4.73%	4.69%
Managerial technical (II)	27.80%	26.06%	28.14%	27.91%
Skilled nonmanual (IIIN)	24.71%	25.09%	24.63%	24.78%
Skilled manual (IIIM)	18.99%	20.11%	18.77%	18.25%
Semi-skilled manual (IV)	17.73%	17.97%	17.68%	18.37%
Unskilled manual (V)	5.86%	6.03%	5.82%	5.78%
Armed forces	0.21%	0.18%	0.22%	0.22%
Health:				
Long-standing illness	44.53%	45.52%	44.34%	44.29%
Very good health	33.62%	33.41%	33.66%	33.21%
Good health	42.44%	41.30%	42.40%	42.93%
Fair health	18.57%	19.44%	18.40%	18.11%
Bad health	4.43%	4.60%	4.40%	4.56%
Very bad health	1.16%	1.24%	1.14%	1.19%
Additional controls:				
White				89.21%
Education[a]				4.03 (2.15)
North of England				49.67%
Urban				13.67%
Suburban				43.80%
Rural				17.51%
Urbanization missing				25.03%
Number of bedrooms				2.97 (0.97)
Current smoker				25.10%
Hours per week sport[b]				0.96 (1.37)
Days vigorous physical activity in last 4 weeks				2.74 (6.06)

[a]Highest educational qualification ranging from 1 = Higher National Diploma/Certificate, Degree or equivalent, to 7 = No qualification.
[b]Hours of sport per week was grouped into six categories ranging from 0 = None to 5 = 7 hours or more per week.

Methods

Participants

Participants were drawn from the Health Survey for England (HSfE) (16), a repeated cross-sectional health examination of a nationally representative random sample of adults and children living in private households in England. The sampling and data collection methodology are described elsewhere (16). This study utilized 13 independent annual surveys with identical measures conducted from 1995 to 2007. The study sample was composed of 100,152 adults ($\geq$16 years) aged 47.6 (SD = 17.7) on average (53.1% female), as shown in Table 1. Of this group, a subsample of 34,052 participants (see Table 1 for characteristics) was examined separately to evaluate the impact of including a broad set of additional control variables on the results of the study.

Measurements

Standing height was assessed using a portable stadiometer and body weight was measured using a portable electronic scales calibrated for the HSfE (16). These readings were used to estimate BMI values in kg/m^2. Ambient indoor air temperature in the participant's residence was gauged using a digital thermometer. The thermometer was placed on a surface where the measurement probe was positioned so that it

TABLE 2 Results of fully adjusted regression analyses assessing the association between ambient indoor temperature levels and BMI in the complete HSfE sample, winter and non-winter subsamples, early (1995-2000) and later (2001-2007) survey wave samples, and subsample with additional control variables

Variables	Full sample[a] (*N* = 100,152) *b* (SE)	Winter sample[a] (*N* = 23,755) *b* (SE)	Non-winter sample[a] (*N* = 76,397) *b* (SE)	1995 - 2000 sample[a] (*N* = 52,494) *b* (SE)	2001 - 2007 sample[a] (*N* = 47,658) *b* (SE)	Additional controls[b] (*N* = 34,052) *b* (SE)
Ambient indoor temperature group						
19-20.5°C	0.002 (0.043)	−0.017 (0.076)	0.002 (.053)	−0.043 (0.056)	−0.044 (0.067)	0.097 (0.076)
20.5-21.5°C	−0.087 (0.049)	−0.055 (0.096)	−0.103 (0.059)	−0.125 (0.065)	−0.047 (0.075)	−0.030 (0.086)
21.5-23°C	−0.133[e](0.047)	−0.032 (0.094)	−0.163[e] (0.06)	−0.056 (0.063)	−0.204[e] (0.071)	−0.035 (0.081)
Over 23°C	−0.233[e](0.053)	−0.284[d] (0.131)	−0.240[e] (0.06)	−0.250[e] (0.071)	−0.209[e] (0.08)	−0.191[d] (0.091)

[a]Analysis adjusted for: age, gender, social class, long-standing illness, self-rated health, and month and year of assessment.
[b]Analysis adjusted for: age, gender, social class, long-standing illness, self-rated health, month and years of assessment, ethnicity, education, location, urbanization, number of bedrooms in residence, smoking, and physical activity.
[c]Base category for analysis is "<19°C."
[d]$P < 0.05$
[e]$P < 0.01$.

did not come in contact with any object (e.g., hanging over the edge of a table). After 5 min the study nurse recorded the ambient temperature correct to one decimal place (16).

Statistical analyses

The temperature variable was divided approximately into quintiles. The characteristics of those in the high (over 23°C) temperature group and those in other temperature groups are detailed in Table 1. Multiple regression analyses were used to contrast the BMI levels of each of the four highest groups (i.e., 19–20.5°C; 20.5–21.5°C; 21.5–23°C, and over 23°C) with those living in temperatures below 19°C. All analyses were adjusted for demographic and health variables: age, gender, social class, presence of long-standing illness, and self-rated health (from 1 = very good to 5 = very bad), as detailed in Table 1. To adjust for seasonality effects and secular trends, month and year dummies were included in all analyses.

Three robustness tests were conducted. First, the association between indoor temperatures and BMI was examined separately for winter and non-winter months. This analysis was conducted to ensure that a link between high indoor temperatures and low BMI did not reflect the impact of increased activity during the summer months (17). Next, the temperature–BMI link was examined separately for the years 1995–2000 (52.5% of sample) and 2001–2007 (47.5% of sample) to test whether this relationship was robust to secular trends in weight gain and indoor air temperatures. Finally, hierarchical regression analysis was used to test the potential impact of adjustment for additional control variables (i.e., ethnicity, education, location, urbanization, bedrooms, health, smoking, physical activity) on the association between BMI and indoor temperature.

Results

An unadjusted model showed that compared with the lowest temperature category (ambient indoor temperatures under 19°C; Mdn = 17.9) those living the highest temperature quintile (above 23°C; Mdn = 24.2) had reduced BMI levels ($b = -0.175$, SE = 0.049, $P < 0.001$). The intermediary temperature quintile groups (i.e., 19–20.5°C; 20.5–21.5°C; 21.5–23°C) did not differ in their BMI levels from those residing below 19°C. The association between living in a domestic environment above 23°C and a low BMI was strengthened after adjusting for the participants' age, gender, social class, health, and year and month of assessment ($b = -0.233$, SE = 0.053, $P < 0.001$), as shown in Table 2. In terms of magnitude, this association was found to be 35% as large as the social gradient in BMI (i.e., moving from social class I to V).

The link between temperatures above 23°C and reduced BMI was found to be similar in winter ($b = -0.284$, SE = 0.131, $P < 0.05$) and non-winter months ($b = -0.240$, SE = 0.060, $P < .001$), and in early ($b = -0.250$, SE = 0.071, $P < 0.001$) and later ($b = -0.209$, SE = 0.08, $P < .01$) survey waves (see Table 2). Further robustness tests in a subsample of 34,052 participants showed an association between indoor temperatures above 23°C and a lower BMI ($b = -0.198$, SE = 0.091, $P < 0.05$) after adjustment for the same controls as the main model. This association was unaffected by further adjustment for a comprehensive range of control variables ($b = -0.191$, SE = 0.091, $P < 0.05$), as shown in Table 2.

Discussion

This is the first study to directly examine the association between objectively recorded indoor household temperatures and population BMI levels. The main finding of this study was that high indoor ambient temperatures predicted lower BMI levels in unadjusted and adjusted analyses of 100,152 English adults. This association persisted in winter months and after consideration of a large set of potential confounding variables including health behaviors. Crucially, this finding is consistent with the suggestion that a negative energy balance emerges at high ambient temperatures where appetite is suppressed, food intake is diminished and energy expenditure is raised (10-12,15).

In contrast to this idea, some researchers have proposed that reduced exposure to thermal cold in recent decades may have had disadvantageous consequences leading to less energy expenditure on metabolic heat production, a positive energy balance, and an increase in weight gain at the population level over several decades (1,2). The current study finds little support for this notion. BMI levels did not decline as indoor temperatures dropped from 23°C to below 19°C, potentially because the excess energy expended to maintain thermal homeostasis at low temperatures is counterbalanced by increased calorific intake (11-13).

Whilst the large sample in the current study provides sufficient power to identify effects of temperature variations on BMI, the study is limited in several respects. Firstly, reverse causation is possible as evaporative cooling is less effective at higher BMI levels and adipose tissue has an insulating effect that could act to reduce the upper threshold for thermal comfort (4,18,19). Both body fat and clothing levels would need to be considered to produce an accurate individual-level estimate of the TNZ (4). If a substantial portion of the sample was wearing light clothing this group would have a raised upper TNZ threshold, leading to an underestimate of the magnitude of the effect of high indoor temperatures on BMI (where a 23°C cut-off is used).

In conclusion, this study provides the first evidence to suggest that high ambient temperatures in the home are linked to population BMI levels. Ambient temperatures above the TNZ represent an underexamined environmental factor that could have pronounced long-term effects on energy balance and potentially contribute to weight loss (20).

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