A critical review of the effectiveness of electric fans as a personal cooling intervention in hot weather and heatwaves

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Health agencies worldwide have historically cautioned that electric fans accelerate body-heat gain during hot weather and heatwaves (typically in air temperatures ≥35°C). However, guidance published since 2021 has suggested that fans can still cool the body in air temperatures up to 40°C by facilitating sweat evaporation, and therefore are an inexpensive yet sustainable alternative to air conditioning. In a critical analysis of the reports cited to support this claim, we found that although fan use improves sweat evaporation, these benefits are of insufficient magnitude to exert meaningful reductions in body core temperature in air temperatures exceeding 35°C. Health agencies should continue to advise against fan use in air temperatures higher than 35°C, especially for people with compromised sweating capacity (eg, adults aged 65 years or older). Improving access to ambient cooling strategies (eg, air conditioning or evaporative coolers) and minimising their economic and environmental costs through policy initiatives, efficient cooling technology, and combined use of low-cost personal interventions (eg, skin wetting or fan use) are crucial for climate adaptation.

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Introduction

An unprecedented heat dome covered the Pacific northwest area of North America in June, 2021, breaking national temperature records in Canada by almost 5°C and resulting in the deaths of more than 1000 adults, most of whom were aged 65 years or older.[1,2] From March to June, 2022, an unusually early spring heatwave engulfed most of south Asia, with temperatures approaching 50°C in Pakistan and India recording one of the highest-ever average maximum temperatures for April (35·3°C).[3,4] Less than 3 months later, temperatures in the UK reached 40°C for the first time in recorded history, with 46 weather stations recording temperatures in excess of the previous national record (38·7°C).[5] Although such events would have been nearly impossible 40 years ago, record-breaking heatwaves are now expected to occur as frequently as once per decade by 2050.[6] Improving adaptive capacity and reducing susceptibility to heat stress, particularly for heat-vulnerable populations (eg, older adults), are needed to address the increasing health burden of extreme heat.[7]

Evidence-based guidance on interventions for preventing the adverse effects of heat stress is a key component of heat-health adaptation planning. The World Meteorological Organization and WHO describe these heat interventions as strategies to help individuals "maintain their core body temperature within a safe range through appropriate changes in behaviour and activities", "recognize, in themselves and in others, the signs and symptoms of heat stress", and "know what actions to take to reduce heat stress".[8] The most protective among commonly recommended strategies is to directly cool the ambient environment.[9] However, air conditioning is not financially viable for many people[10,11] and, depending on the source of electricity, can contribute to accumulating greenhouse gases, exacerbating planetary warming.[12–15]

Concerns about the economic and environmental burdens of air conditioning have led to calls for increased use of inexpensive, sustainable cooling interventions. Perhaps the most widely advocated are electric fans.[16] Although a fan directed at the body improves convective heat dissipation in cool environments by increasing airflow above the skin surface, this same mechanism means that fans exacerbate heat gain in hot environments (panel).[27,28] For this reason, many health agencies, including the WHO and United States Centers for Disease Control and Prevention, have historically cautioned against the use of fans in high air temperatures (typically ≥35°C).[8,29]

However, newer guidance, including the 2022 report of the *Lancet* Countdown on health and climate change,[30] a 2021 *Lancet* Series on Heat and Health,[16] and heat-advisory information provided by Google,[31] advocates that fans can be used to cool the body in air temperatures up to 40°C depending on humidity and other factors, such as age (panel). These updated temperature limits are primarily based on biophysical modelling reports suggesting that, in environmental conditions reflective of most heatwaves, fan-induced increases in heat gain are outweighed by improvements in the potential for cooling via sweat evaporation.[18,19] Although this modelling technique allows for rapid assessment of the theoretical effect of fans on body–environment heat exchange in a wide array of conditions, it does not allow the user to quantify whether the associated cooling is sufficient to maintain body temperature within safe limits,[25] which WHO considers to be a basic goal of interventions for preventing adverse heat-related health outcomes.[8] This shortcoming is substantial, as improving the potential for heat loss does not guarantee a meaningful reduction in core temperature (panel).

We believe that updated temperature limits for safe and effective electric fan use (eg, pedestal-mounted or ceiling-mounted) have been promoted and implemented too hastily. In this critical review, we extended the modelling studies used to justify electric fan use in air temperatures more than 35°C to show that fans should not be expected to provide meaningful bodily cooling during hot weather and heatwaves, particularly for people with compromised sweating (eg, older adults),[32,33] an interpretation that is consistent with evidence from modelling and laboratory-based heat exposure studies. Furthermore, we examined the implications and limitations of our findings, and the use of biophysical modelling more generally, for informing public guidance on personal cooling interventions. We also considered the importance of ambient cooling and how fans and other sustainable cooling interventions might be used to supplement, rather than replace, air conditioning to reduce the associated costs without compromising protection for the most vulnerable.

Panel: Biophysical basis of electric fans as a cooling intervention

The human thermoregulatory system functions to regulate body temperature within the narrow range required for homoeostasis. Body-temperature regulation is accomplished through complex autonomic and behavioural mechanisms that balance heat exchange between the body and the surrounding environment with the heat generated as a by-product of metabolism.[17] Heat exchange can be subdivided into two major pathways, dry and evaporative. Dry heat exchange describes heat exchange via radiation, convection, and conduction and is dependent on the skin–environment temperature gradient.

See **Online** for appendix

When air temperature is lower than skin temperature, fans accelerate convective heat loss primarily by preventing the formation of a warm boundary layer of stagnant air just above the skin surface, thereby maintaining the widest possible skin–environment temperature gradient and drive for heat exchange.[17] With increases in air temperature, the fan-induced augmentation in dry heat loss is progressively attenuated as ambient and skin temperatures converge. When air temperature exceeds that of the skin (approximately 35°C), fans exacerbate dry heat gain by continuously replacing the relatively cool boundary layer with hot air (appendix p 12).

Fans can still benefit net heat exchange in hot environments despite increasing heat gain by augmenting evaporative heat loss.[18,19] Evaporative heat loss is driven by the evaporation of sweat secreted on the skin surface.[20] The high latent heat of vaporisation of sweat (2426 J/g),[17] alongside maximal sweat rates of 2 L/h or more,[21] make evaporative heat loss the most powerful autonomic cooling mechanism in humans.[17] Importantly, heat transfer is driven by the skin–environment water-vapour pressure gradient, meaning that evaporative heat loss can still occur when air temperature exceeds skin temperature, although it is impeded by increasing ambient humidity.[18] Use of a fan facilitates sweat evaporation by replacing the humid (saturated) boundary layer above the skin with relatively dry air, widening the skin–environment vapour-pressure gradient. The resultant improvement in sweating efficiency (ie, the proportion of secreted sweat that evaporates) means increased evaporative heat loss can be achieved for a given sweat rate.

The effect of a fan on core temperature depends on the ways its effects on heat gain and sweating efficiency modify the whole-body sweat rate required to attain heat balance, which reflects a state where heat loss equals heat gain and body temperature is stable. This concept follows two well established underpinnings of human thermoregulation. First, during heat stress, sweat rate will increase until either a sufficient rate of heat loss is generated to compensate for total heat gain (ie, compensable conditions) or the required heat loss exceeds the physiological maximum sweat production or the maximum rate of evaporation permitted by the environment (ie, uncompensable conditions).[22] Second, core temperature provides the primary stimulus for sweat production and needs to be increased for evaporative heat loss to occur.[23] Consequently, the increase in core temperature in compensable conditions reflective of most hot weather is dependent on the whole-body sweat rate required for heat balance (appendix p 23).[24] In conditions in which fans reduce the required sweat rate, core temperature will be lower with fan use than without fan use. This scenario is expected to occur in hot–humid weather (eg, characteristic of extremes in tropical or subtropical regions) where air and skin temperatures are similar but large gains in sweating efficiency are possible. By contrast, a fan-induced increase in required sweat rate will lead to increased core temperature, a scenario likely to occur in very hot and dry environments in which dry heat gain is substantial and produced sweat readily evaporates even without fan use (eg, arid or semi-arid regions).

Since 2015, there has been increased use of biophysical modelling to evaluate the theoretical physiological effects of fans in a wide array of ambient conditions reflective of global temperature extremes.[18,19,25,26] For example, Morris and colleagues[19] estimated the ambient conditions under which fan use augments the potential for evaporative heat loss (ie, the rate of evaporation achievable when whole-body sweat rate is at its assumed physiological maximum) to a greater extent than it increases dry heat gain.[19] On the basis of this work, the authors proposed simplified, humidity-independent air-temperature limits of 39°C for healthy young adults (aged 18–40 years) and 38°C for healthy older adults (aged 65 years or older); although fan use could ostensibly improve heat dissipation in conditions as hot as 40–42°C if humidity is low.[19] However, their modelling technique does not allow the user to directly quantify the magnitude of body cooling.[25] Furthermore, the authors did not consider that an improvement in heat-exchange potential does not guarantee a meaningful reduction in the increase in sweat rate and, therefore, core temperature required for heat balance. For example, we found that required sweat rate was altered by –37% to 15% with fan use in air temperatures between 35°C and 38°C (humidity 10% to 70%), despite improvements in the potential for heat dissipation in these conditions (appendix p 19).

Estimating the effect of fan use on core temperature

The efficacy of a personal cooling intervention depends on its ability to promote heat exchange between the body and the surrounding environment to facilitate maintenance of the internal temperature of the body within the relatively narrow range required for homoeostasis.[16] Although minor deviations from optimal temperatures due to physical activity or exposure to warm weather generally have little acute health risk, extreme increases in core temperature or even small-to-moderate increases sustained for extended periods (eg, several days of a heatwave) increase the risk of serious health conditions, including heatstroke, major cardiovascular events, and kidney injury, among others.[33,34] These risks are not evenly distributed across populations. Older adults (aged 65 years or older), for example, are at greater risk of heat-related injury than young adults (aged 18–40 years) due to age-related impairments in body-temperature regulation and declines in bodily systems supporting thermoregulation and homoeostasis (eg, the circulatory and renal systems).[33]

To evaluate the effectiveness of fans for body cooling, we used the simplified heat-balance modelling approach on which Jay and colleagues[18] based their analysis of the effect of fans to estimate the rate of whole-body sweat production required to achieve heat balance,[19] a state of thermal equilibrium in which heat gain by the body is fully compensated by heat loss (panel). The required whole-body sweat rate for heat balance was estimated for young adults and older adults dressed in light summer clothing and seated in ambient air temperatures ranging from 30°C to 50°C, relative humidities ranging from 10% to 90%, and with and without a pedestal fan generating an air velocity of 4·5 m/s at the front of the body. We then extended those models using data from a laboratory-based heatwave simulation study[35,36] and a classic conceptual model of thermoregulation[22,24] to estimate the increase in core temperature, the primary physiological

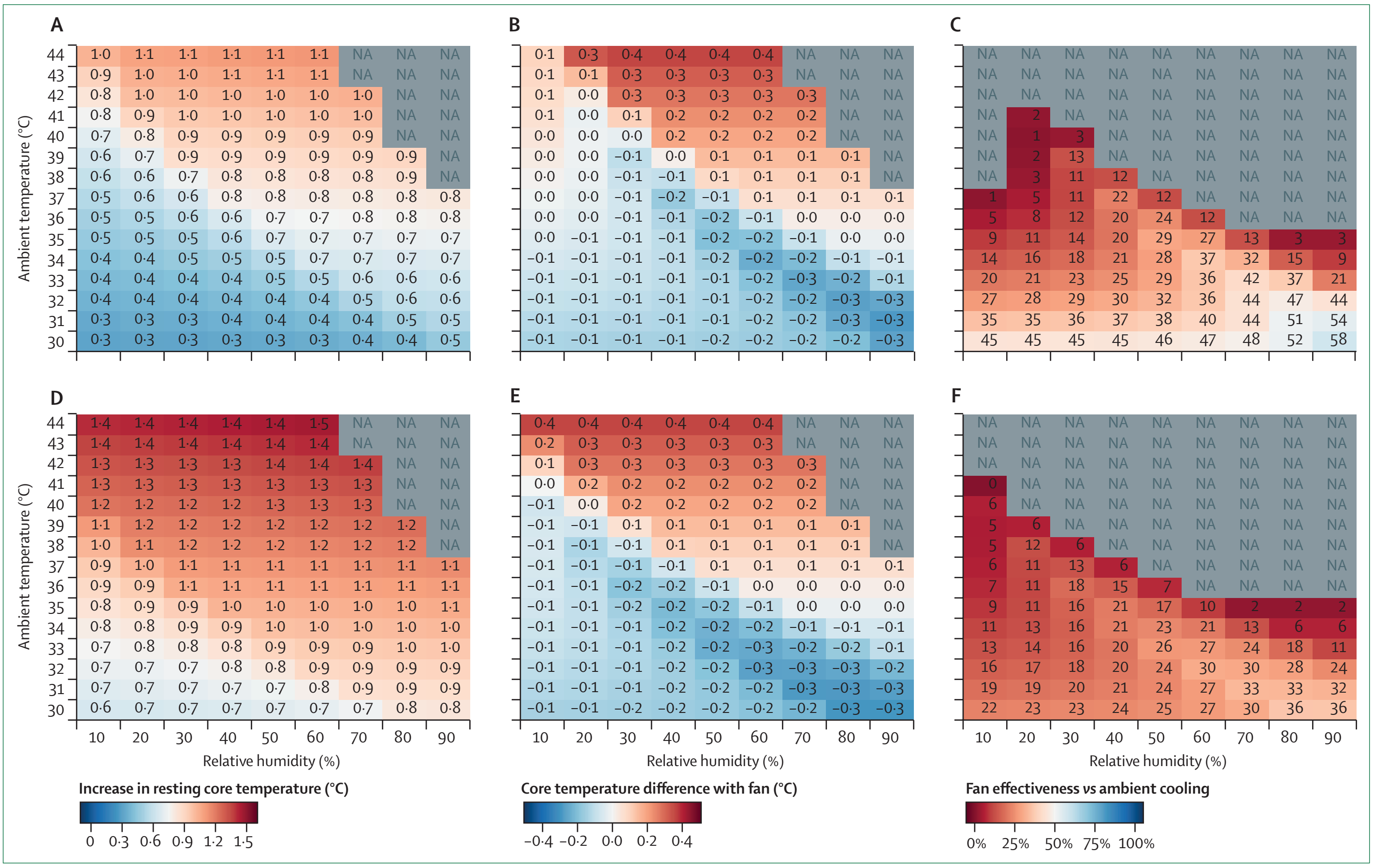


Figure 1: **Estimated resting core temperatures during heat exposure with and without electric fan use**

(A) Estimated core temperature for a hypothetical young adult (aged 18–40 years) wearing light summer clothing resting in the seated position without an electric fan. (B) Estimated difference in core temperature of a hypothetical young adult with use of a fan generating an air velocity of 4·5 m/s at the front of the body from 1 m away, calculated as the core temperature estimated in the fan use model (not shown) minus that in the no fan use model (from panel A). The model assumed that airflow was being generated evenly across the front surface of the body. (C) Estimated effectiveness of fan use relative to direct ambient cooling (eg, air conditioning) sufficient to maintain a thermoneutral ambient environment (approximately 22–24°C) in a hypothetical young adult, calculated as the fan-induced reduction in core temperature (from panel B) divided by the core temperature change in the no fan use model (from panel A). (D–F) Estimated change in core temperature and effectiveness of fans for a hypothetical older adult (aged 65 years or older) via the same methods as described for a young adult. Data were generated with the simplified heat balance model (appendix pp 3–29). NA=not applicable.

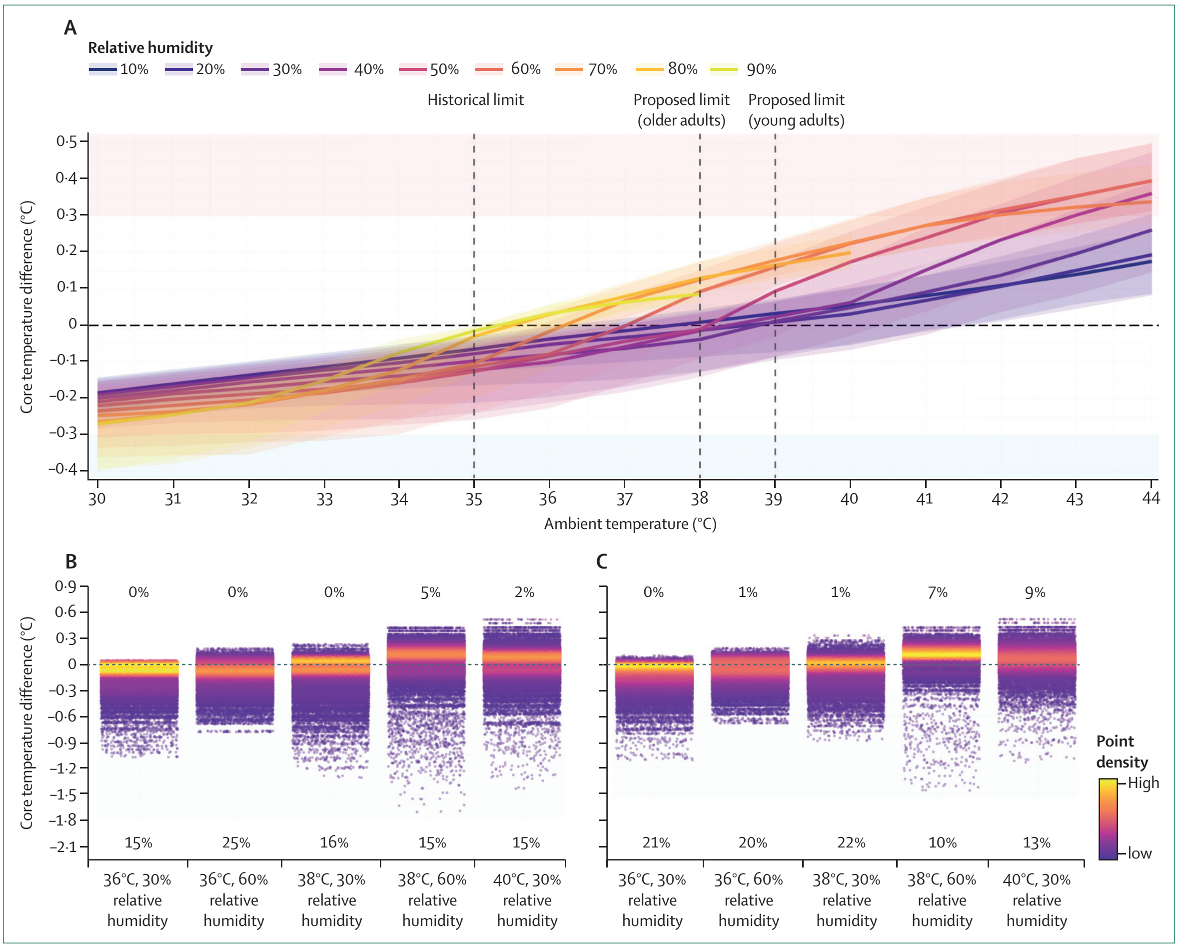


***Figure 2:* Sensitivity analyses evaluating the effect of adjusting key modelling assumptions on the estimated effectiveness of fans**

(A) Estimated change in core temperature with fan use (fan use model *vs* no fan use model) as a function of ambient air temperature and relative humidity. Data are median (IQR) of 116 640 models produced via the simplified heat balance model but with varying inputs for key assumptions. Vertical lines signify the historically recommended air temperature limit for fan use (35°C),[8] and the newer limits proposed by Jay and colleagues[16] for healthy young adults (aged 18–40 years; 39°C) and older adults (aged 65 years or older; 38°C). (B) Distribution of the model estimates for the change in core temperature with fan use for young adults, under specific environmental conditions. (C) Distribution of the model estimates for the change in core temperature with fan use for older adults, under specific environmental conditions. Fan use was considered beneficial if it reduced estimated core temperature by ≥0·3°C[37,38] or if conditions were compensable (ie, required sweat rate was less than or equal to maximal sweat rate and heat balance could be achieved) with fan use but not without. The percentage of models in which fans were beneficial under these criteria is shown below each distribution. The percentage of models in which fans were considered detrimental (ie, increased core temperature by ≥0·3°C or prevented heat balance) under these criteria is shown above each distribution. Models for which either fan or no fan condition was uncompensable are not shown. Details of the sensitivity analyses are provided in the appendix (pp 34–57).

stimulus for sweating, needed to achieve the required sweat rate (appendix pp 3–33).

Comparing estimated core temperatures with and without fan use allowed us to predict the effectiveness of fans for body cooling. Although increased body temperatures can exacerbate the risk of acute injury,[8,34] what constitutes a dangerous increase (especially when sustained during extended periods) and how this threshold differs in vulnerable groups (eg, older adults) is less clear.[33] To provide a comprehensive assessment of the cooling potential of electric fans, we therefore quantified their effectiveness in four ways. Based on the minimal clinically significant difference proposed by Morris and colleagues[37] and the typical day-to-day variation in core temperature,[38] our primary analysis considered fans to be beneficial in conditions in which our modelling estimated fan use would reduce core temperature by 0·3°C or more (or, equivalently, lessen the expected increase in core temperature by ≥0·3°C). That is, we considered 0·3°C to be the smallest fan-induced reduction that could be expected to improve wellbeing in exposed individuals—anything less might be considered negligible or trivial (ie, effectiveness criterion 1). We also compared the fan-induced reduction in core temperature with the expected increase that would have been prevented with direct ambient cooling sufficient to maintain a thermoneutral environment (approximately 22–24°C; ie, effectiveness criterion 2).

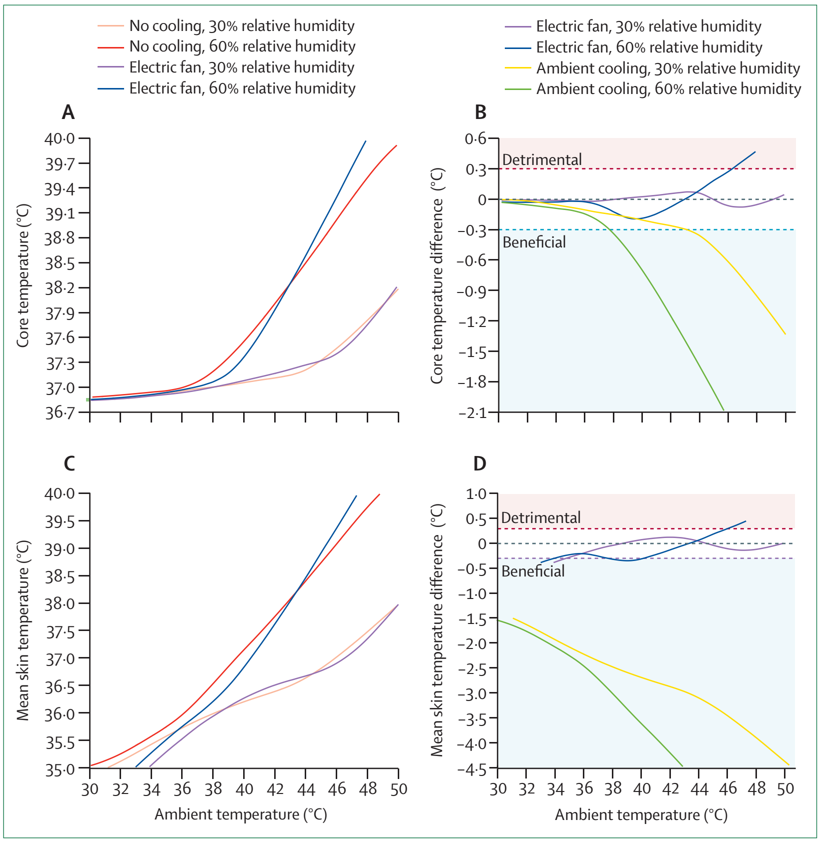


***Figure 3:* Estimated core and skin temperatures with electric fan use in the modelling study by Tartarini and colleagues**[26]

(A) Estimated core temperatures for a hypothetical adult (age not specified) resting in ambient conditions ranging from 30–50°C with 30% and 60% relative humidity with and without fan use (front-facing fan generating an air velocity of 4·0 m/s).[26] (B) Estimated difference in core temperature with fan use or direct ambient cooling (eg, air conditioning). The difference with fan use was calculated as the core temperature in the fan use model minus that in the no fan use model. The difference with ambient cooling was calculated as the core temperature under thermoneutral conditions, which would have been maintained with air conditioning, minus the increase in the no fan model. (C, D) Estimated effect of fans and ambient cooling on skin temperature via the same methods as previously described. Thermoneutral skin temperature was estimated at 33·5°C (not depicted).[41,42] Data were generated via the model developed by Gagge,[43] as reported in the study by Tartarini and colleagues.[26] The depicted curves were reconstructed from that report with freely available software (appendix p 58).[44]

Direct ambient cooling in this context could be any method for reducing air temperature (eg, radiant or evaporative coolers), but we referred to it primarily as air conditioning as air conditioning is the most widely recommended and discussed ambient cooling strategy worldwide.[8,15,16,30,39] In our secondary analyses, we estimated the effectiveness of fans for restricting core temperature increases to 38°C or less, a commonly recommended upper limit for occupational heat exposure (ie, effectiveness criterion 3),[8] and for preventing unchecked hyperthermia from occurring (ie, when the required sweat rate for heat balance exceeds the physiological maximum; effectiveness criterion 4).

The estimated reduction in core temperature with fan use did not meet the 0·3°C threshold for a minimally beneficial cooling effect in air temperatures higher than 33°C in either young or older adults (figure 1). Moreover, the fan-induced cooling effect was less than 30% of that expected with ambient cooling at air temperatures at or more than the historical 35°C limit. This finding means, for example, that an older adult resting in 36°C and 40% relative humidity would be expected to have a 1·1°C increase in core temperature without a fan and a 0·9°C increase with a fan. Although fan use might therefore be expected to cool the body 0·2°C (18%), a 1·1°C increase could have been prevented had that individual remained in an air-conditioned environment. Even a 3–6°C reduction in air temperature could elicit a meaningful reduction in core temperature (figure 1A, D).

When their ability to prevent core temperature from exceeding 38°C was evaluated (appendix p 30), fans were estimated to be detrimental for young adults in air temperatures more than 40·8°C and trivial in temperatures less than this threshold. For older adults, fans were beneficial in conditions ranging from 39·2°C to 40·4°C with 24% relative humidity or less. However, the estimated fan-induced reduction in core temperature did not exceed 0·1°C. Conversely, fan use was detrimental in conditions ranging from 36·9°C to 39·1°C with 26% relative humidity or more, increasing core temperature up to 0·5°C from that estimated without fan use. In no conditions were fans effective for maintaining heat balance; rather, fans were expected to prevent heat balance, leading to unchecked increases in core temperature, in air temperatures more than 48·7°C in young adults and more than 45·0°C in older adults (appendix p 31).

We then conducted a sensitivity analysis to evaluate the robustness of our inferences to key assumptions made in the modelling process. The simplified heat-balance model is an extension of partitional calorimetry, a technique originally designed to estimate heat exchange in a resting or exercising individual from numerous physical and physiological measurements (eg, metabolic rate or whole-body sweat rate) by use of standard equations.[40] By replacing key measurement inputs with estimates from the literature, Jay and colleagues[18] extended these predictive equations to explore the theoretical effects of fan use on whole-body heat exchange.[19] Independently adjusting key assumptions had mild-to-substantial effects on the conditions under which fan use was estimated to be beneficial (appendix pp 35–53). However, most of the 116 640 generated models supported our interpretation that fans should not be expected to reduce core temperature to a meaningful extent in air temperatures of 35°C or more (figure 2) or provide cooling similar to air conditioning (appendix pp 54–55). Furthermore, only a small proportion of models estimated that fans would be effective for maintaining core temperature less than 38°C or preventing unchecked hyperthermia (appendix p 57).

Our simple analyses showed that fan use has little effect on core temperature in hot conditions (figures 1, 2), despite improvements in the potential for cooling via sweat evaporation (appendix p 19). This finding is

	Sample size	Sex	Age, years	Duration of heat exposure, min	Ambient conditions*		Increase in core temperature†			Effect vs ambient cooling‡
					Temperature	Humidity	No fan	Fan	Mean difference	
Heat-event simulations§										
Morris and colleagues (2019)[37]	12	No female participants, 12 male participants	29	120	40°C; 47°C	50%; 10%	0·4°C (0·3); 0·3°C (0·2)	0·3°C (0·2); 0·6°C (0·3)	–0·1 (–0·2 to 0·0); 0·3 (0·1 to 0·5)¶	25%
Morris (2018)[45]‖	12	No female participants, 12 male participants	28	120	46°C	11%	0·4°C (0·2)	0·4°C (0·3)	0·0 (–0·1 to 0·1)	0%
Cramer and colleagues (2020)[46]‖	9	Five female participants, four male participants	68	120	42°C	34%	0·9°C (0·2)	0·9°C (0·2)	–0·1 (–0·1 to 0·1)	11%
Humidity-ramp protocols**										
Ravanelli and colleagues (2017)[47]	8	No female participants, eight male participants	24	120	36°C; 42°C	28% to 91%; 22% to 67%	0·4°C (0·2); 0·9°C (0·1)	0·3°C (0·2); 0·6°C (0·1)	–0·1 (–0·2 to 0·0); –0·3 (–0·4 to –0·2)††	25%; 33%
Gagnon and colleagues (2017)[48]	9	Four female participants, five male participants	26	100	42°C	30% to 70%	1·2°C (0·2)	1·0°C (0·3)	–0·2 (–0·3 to –0·1)	17%
Gagnon and colleagues (2016)[49]	9	Six female participants, three male participants	68	100	42°C	30% to 70%	1·3°C (0·2)	1·6°C (0·5)	0·3 (0·2 to 0·4)¶	..
Pilot work‡‡										
Morris (2018)[50]	..	..	"Young"	..	36°C; 45°C	70%; 50%	..	..	–0·1; 0·2	..

Data are mean (SD) or mean (95% CI) as provided in the studies or approximated in analyses. Data were extracted from text and tables directly or from figures via freely available software (appendix pp 59–60).[44] *Ambient conditions expressed as absolute air temperature and relative humidity. †Change in core temperature calculated as the change from baseline to the last measured timepoint during exposure. ‡Effectiveness of fans versus direct ambient cooling (eg, air conditioning) was established for studies in which fan use reduced core temperature. This measure was calculated as the point estimate for fan-induced reduction in core temperature divided by the point estimate for the increase in core temperature during exposure without fan use, which would have been prevented if the person was exposed to ambient cooling sufficient to maintain a thermoneutral environment (approximately 22–24°C). §Heat-event simulation studies were those in which resting participants were exposed to stable environmental conditions reflective of historical extreme heatwaves. ¶Point estimate indicated that fan use was detrimental, defined as ≥0·3°C increase in core temperature with fan use.[37,38] ‖In the fan condition, people were allowed to apply water to the skin ad libitum (in Morris) or the shirt of the participants was soaked with water (in Cramer and colleagues). Combined fan and supplemental skin or cloth wetting were compared with no cooling intervention (ie, dry shirt and no fan). **In humidity-ramp studies, participants were first exposed to increased air temperatures with low relative humidity. Humidity was then increased every 2 min to 5 min. ††Point estimate indicated that fan use was beneficial, defined as ≥0·3°C reduction in core temperature with fan use.[37,38] ‡‡A reply letter to the editor by Hospers and colleagues[50] reported data from pilot work by Morris and colleagues.[37] These data were included as fan use was recommended in the conditions (36°C and 70% relative humidity) under the newly proposed air-temperature limits.[16]

Table 1: **Laboratory-based studies of the effectiveness of pedestal fans in reducing core temperature in resting people**

supported by modelling information published in 2022 that estimated similar increases in core and skin temperatures with and without fan use during exposure to moderate-to-high air temperatures (figure 3)[26] and laboratory-based studies published from 2016 onwards in which reductions in core temperature with fan use in simulated heat-wave conditions were small and unlikely to be clinically meaningful (table 1).[37,45–50]

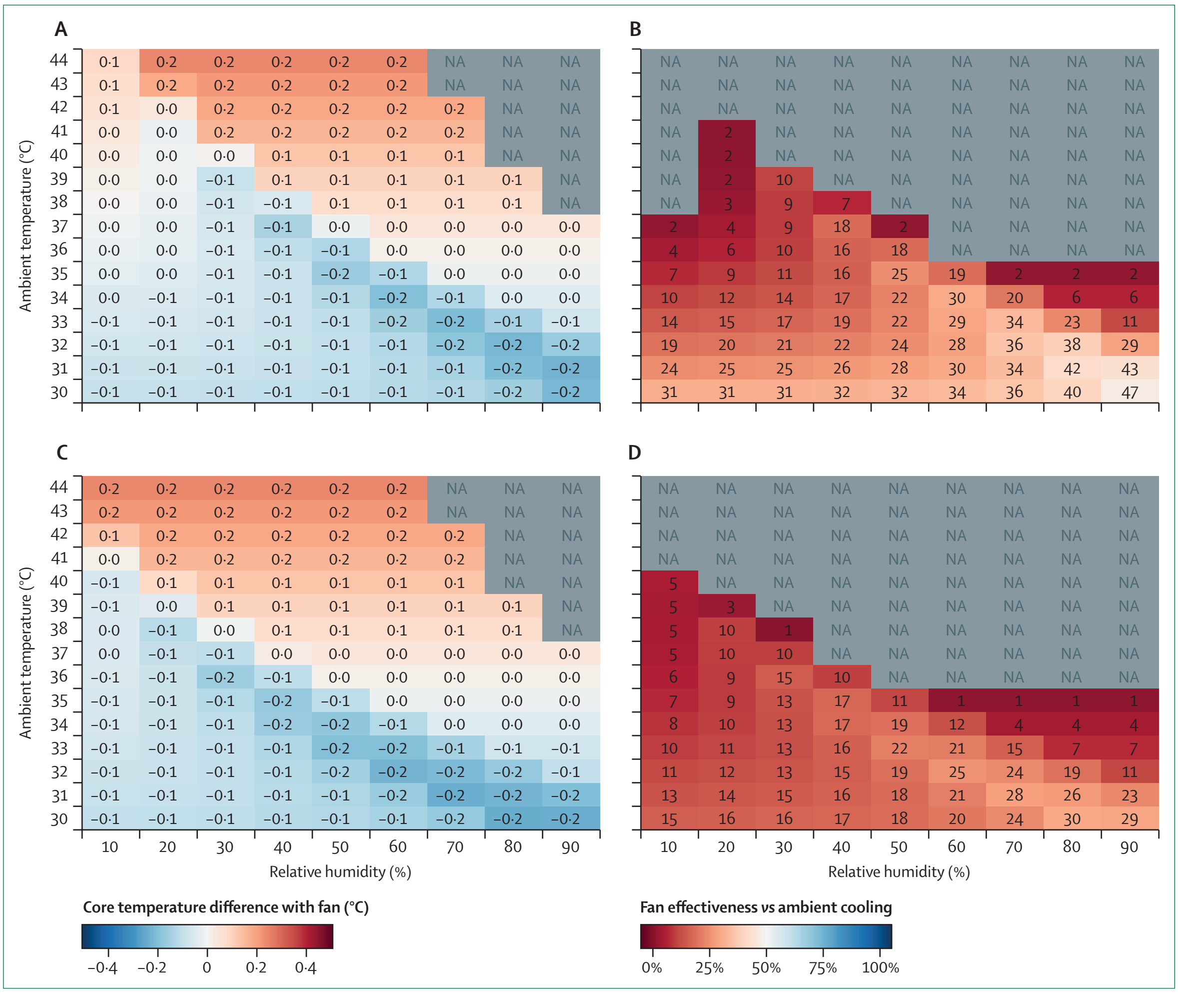
Implications for heat-health guidance and policy

Available evidence does not support electric fan use as an effective personal cooling intervention during hot weather and heatwaves. Although we focused on reports evaluating the physiological effects of fans[18,19,26,37,45–50] as these reports have been the basis of recommendations since 2021,[16,30,31,39] our findings are consistent with seminal studies conducted more than 80 years ago[27,28,51] and epidemiological data indicating that access to fans was not associated with reduced risk of heat-related mortality during heatwaves.[9,52] On the basis of the totality of available evidence, we refute the claim that electric fans are effective for body cooling in temperatures of 35°C or more and advise against their use as a standalone cooling intervention, especially for individuals with reduced physiological capacity to respond to heat stress.[32,33] Proposed changes to heat-health guidance to recommend fans during hot weather and heatwaves should be deferred until such time that there exists sufficient empirical evidence to justify their use in these conditions.

Our analyses also have implications for the use of biophysical modelling for informing public health guidance. Although we believe that these techniques can provide useful information on the theoretical biophysical effects of cooling interventions, there are numerous limitations that render model outputs inappropriate for direct use in public health heat-wave policy documents.[16] A key issue is that modelling studies have quantified the benefits of fans dichotomously regarding whether use improves environmental determinants of heat exchange, rather than the direct effect on core temperature (panel). However, there are other limitations that warrant discussion.

Airflow supplied by the fan

One such limitation is that models have generally assumed that individuals are seated approximately 1 m from a fan generating an air velocity of 3·5–4·5 m/s at the front of the body.[18,19,25,36] These conditions are ideal



A

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	0·1	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
43	0·1	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
42	0·1	0·0	0·2	0·2	0·2	0·2	0·2	NA	NA
41	0·0	0·0	0·2	0·2	0·2	0·2	0·2	NA	NA
40	0·0	0·0	0·0	0·1	0·1	0·1	0·1	NA	NA
39	0·0	0·0	−0·1	0·1	0·1	0·1	0·1	0·1	NA
38	0·0	0·0	−0·1	−0·1	0·1	0·1	0·1	0·1	NA
37	0·0	0·0	−0·1	−0·1	0·0	0·0	0·0	0·0	0·0
36	0·0	0·0	−0·1	−0·1	−0·1	0·0	0·0	0·0	0·0
35	0·0	0·0	−0·1	−0·1	−0·2	−0·1	0·0	0·0	0·0
34	0·0	−0·1	−0·1	−0·1	−0·1	−0·2	−0·1	0·0	0·0
33	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·1	−0·1
32	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2
31	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2
30	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2

B

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	NA	NA	NA	NA	NA	NA	NA	NA	NA
43	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	NA	NA	NA	NA	NA	NA	NA	NA	NA
41	NA	2	NA	NA	NA	NA	NA	NA	NA
40	NA	2	NA	NA	NA	NA	NA	NA	NA
39	NA	2	10	NA	NA	NA	NA	NA	NA
38	NA	3	9	7	NA	NA	NA	NA	NA
37	2	4	9	18	2	NA	NA	NA	NA
36	4	6	10	16	18	NA	NA	NA	NA
35	7	9	11	16	25	19	2	2	2
34	10	12	14	17	22	30	20	6	6
33	14	15	17	19	22	29	34	23	11
32	19	20	21	22	24	28	36	38	29
31	24	25	25	26	28	30	34	42	43
30	31	31	31	32	32	34	36	40	47

C

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	0·2	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
43	0·2	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
42	0·1	0·2	0·2	0·2	0·2	0·2	0·2	NA	NA
41	0·0	0·2	0·2	0·2	0·2	0·2	0·2	NA	NA
40	−0·1	0·1	0·1	0·1	0·1	0·1	0·1	NA	NA
39	−0·1	0·0	0·1	0·1	0·1	0·1	0·1	0·1	NA
38	0·0	−0·1	0·0	0·1	0·1	0·1	0·1	0·1	NA
37	0·0	−0·1	−0·1	0·0	0·0	0·0	0·0	0·0	0·0
36	−0·1	−0·1	−0·2	−0·1	0·0	0·0	0·0	0·0	0·0
35	−0·1	−0·1	−0·1	−0·2	−0·1	0·0	0·0	0·0	0·0
34	−0·1	−0·1	−0·1	−0·2	−0·2	−0·1	0·0	0·0	0·0
33	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·1	−0·1	−0·1
32	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2	−0·2	−0·1
31	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2	−0·2
30	−0·1	−0·1	−0·1	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2

D

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	NA	NA	NA	NA	NA	NA	NA	NA	NA
43	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	NA	NA	NA	NA	NA	NA	NA	NA	NA
41	NA	NA	NA	NA	NA	NA	NA	NA	NA
40	5	NA	NA	NA	NA	NA	NA	NA	NA
39	5	3	NA	NA	NA	NA	NA	NA	NA
38	5	10	1	NA	NA	NA	NA	NA	NA
37	5	10	10	NA	NA	NA	NA	NA	NA
36	6	9	15	10	NA	NA	NA	NA	NA
35	7	9	13	17	11	1	1	1	1
34	8	10	13	17	19	12	4	4	4
33	10	11	13	16	22	21	15	7	7
32	11	12	13	15	19	25	24	19	11
31	13	14	15	16	18	21	28	26	23
30	15	16	16	17	18	20	24	30	29

Figure 4: **Estimated effect of a small pedestal or ceiling fan on resting core temperature**
(A) Estimated difference in core temperature in a hypothetical young adult (aged 18–40 years) with a small electric pedestal or ceiling fan generating an air velocity of 1·0 m/s from 1 m away, calculated as the core temperature estimated in the fan use model minus that in the no fan use model. The young adult was assumed to be resting in the seated position. The model also assumed that airflow was being generated evenly across the front surface of the body. (B) Estimated effectiveness of fan use relative to direct ambient cooling (eg, air conditioning) sufficient to maintain a thermoneutral ambient environment (approximately 22–24°C), calculated as the fan-induced reduction in core temperature (from panel A) divided by the core temperature change in the no-fan model. (C, D) Estimated change in core temperature and effectiveness of a small pedestal or ceiling fan for a hypothetical older adult (aged 65 years or older). Data were generated with the simplified heat balance model (appendix p 32). NA=not applicable.

for heat exchange but are probably not reflective of real-world situations. This airflow cannot be attained by many marketed pedestal or ceiling fans,[53,54] can cause discomfort unrelated to thermal factors (eg, skin drying or eye irritation),[55] and restricted mobilisation and the positioning of the fan can impede many activities of daily living. As such, the estimated reduction in core temperature achievable by fans in our analyses probably overestimates the true effect in most situations.

To evaluate the effect of fan use on core temperature responses in more reasonable conditions, we modelled the cooling effect of a fan generating an air velocity of 1·0 m/s, which was considered to reflect a comfortable air speed[56] and the approximate flow generated by a ceiling fan.[26,54] In these conditions, our model estimated that fan use would not reduce core temperature by 0·3°C or more in air temperatures more than 30°C (figure 4). This finding is consistent with those of Tartarini and colleagues,[26] who estimated that a standard ceiling fan reduced hourly sweat losses of 37 mL or less in conditions reflective of global temperature extremes. On the basis of our estimates, a reduction in sweat rate of this magnitude translates to a maximal reduction in core temperature of less than 0·1°C (appendix p 23).

Individual variation in physiological responses to heat exposure

Another issue is that current models do not adequately consider the variation in physiological responses to heat exposure associated with age, sex, race, ethnicity, morphology, hydration status, physical fitness, presence of chronic health conditions, history of heat exposure (ie, acclimation or acclimatisation), worn clothing, other factors, or potential interactions between these factors.[33,57–67] For example, ageing and physical inactivity are associated with progressive declines in thermoregulatory function and the capacity for heat dissipation is generally lower in female individuals than in male individuals at any age.[58,59] Older adults also exhibit blunted thermoregulatory responses to dehydration,[60,61] could have chronic health conditions or be taking medications impairing body temperature and fluid regulation,[33,57] and are more likely to overdress than young adults.[64]

There is also considerable global heterogeneity in heat-related mortality,[68] with individuals living in hot climates less susceptible to the adverse effects of heatwaves than individuals living in cool climates.[69] Despite these considerations, model outputs have been applied to the global population,[19] assuming, for example, that the biophysical determinants of heat exchange and body-temperature regulation are the same for physically fit young female individuals in western Canada and sedentary male individuals in India.

Uncertainty arising from modelling assumptions

Findings from modelling studies have generally been presented without quantification of uncertainty, which can be assessed through sensitivity analyses of key assumptions.[70,71] Such analyses are crucial in supporting or refuting model-based inference and in public health decision making.[71,72] The dearth of reported sensitivity analyses is a key issue as biophysical modelling relies on reasonable assumptions for numerous physical and physiological variables to derive accurate estimates of the physiological effects of fan use or other cooling interventions. In current applications, inputs for many key parameters are based on small studies (some with as few as three participants), often in experimental conditions that are not reflective of hot weather.[18,19] Even minor adjustments to these assumptions can have substantial effects on the estimated effectiveness of the modelled cooling intervention (figure 2) and subsequent recommendations. Differences in modelling assumptions[18,19] have led to discrepant advice on conditions in which fans should be used; a 2021 guidance document recommended that fans are most effective in humid conditions,[16] whereas a report by WHO Europe published in the same year indicated that fans are probably better suited to dry environments.[39]

We therefore believe that substantial caution should be exercised when extrapolating model outputs to derive population-level inferences. If these limitations are addressed, we believe that biophysical modelling can be used as an effective and efficient tool to explore options for future research or to extend empirical research to conditions that are ethically or practically unconducive to laboratory-based or field-based study (eg, in individuals particularly susceptible to heat stress, such as infants or people in care homes). This belief does not, however, negate the need for empirical evidence, based on primary data rather than model outputs, in the development of evidence-based recommendations for safe and effective use of personal cooling interventions.

Other potential benefits of fan use

Although fans do not appear to be suitable as a stand-alone intervention for preventing excessive increases in core temperature, they might have other beneficial effects that can be exploited to protect wellbeing during hot weather and heat events, particularly when more powerful cooling interventions (eg, air conditioning) are unavailable.[16,30]

Reducing cardiovascular strain

Most heat-related deaths in the global general population result from major adverse cardiovascular events, particularly in individuals who are already at risk of these events, such as older adults and people with chronic health conditions (eg, heart disease).[33,34] The prevailing theory is that increased core and skin temperatures elicit autonomic and locally mediated responses to divert blood from the central circulation to the skin to facilitate heat dissipation to the environment.[33,34] This process requires increased cardiac work to maintain blood pressure and tissue perfusion, straining the heart and increasing the risk of adverse cardiac events.[33,34] Theoretically, improving sweat evaporation and skin–environment heat transfer with fan use can attenuate cardiovascular strain by reducing skin temperature and skin blood flow,[73–75] even if core temperature is not appreciably altered.

Data from laboratory-based studies are not inconsistent with a meaningful fan-induced reduction in cardiac strain in young adults resting in hot conditions (table 2); often, the point estimate, but not the 95% CI, exceeded a previously suggested criterion for a beneficial reduction in heart rate (ie, ≥5 beats per min).[37] Fan use could therefore be a sustainable way of reducing cardiovascular strain in young adults, especially as the risk of heat-related mortality and morbidity in this population are inherently low.[76] However, the observed effectiveness of fans for reducing cardiovascular strain was no more than 44% of that expected with air conditioning (table 2). Moreover, the two studies of older adults did not support the use of fans for reducing cardiac strain (table 2), although the conditions were hot (40–42°C). Whether fans can be used to reduce cardiovascular strain in older adults in less extreme conditions (eg, <40°C) is an important area of future inquiry.

Improving thermal comfort

In a modelling study published in 2022, Malik and colleagues[56] suggested that fans generating an air velocity of 0·8–1·2 m/s could be used to reduce reliance on air

	Sample size	Sex	Age, years	Duration of heat exposure, min	Ambient conditions*		Increase in core temperature†			Effect *vs* ambient cooling‡
					Temperature	Humidity	No fan, bpm	Fan, bpm	Mean difference	
Heat-event simulations§										
Morris and colleagues (2019)[37]	12	No female participants, 12 male participants	29	120	40°C; 47°C	50%; 10%	18 (9); 12 (8)	10 (5); 32 (11)	–8 (–13 to –2)¶; 20 (13 to 27)‖	44%
Morris (2018)[45]**	12	No female participants, 12 male participants	28	120	46°C	11%	9 (10)	11 (12)	1 (–6 to 8)	··
Cramer and colleagues (2020)[46]**	9	Five female participants, four male participants	68	120	42°C	34%	12 (10)	16 (8)	5 (–3 to 12)††	··
Humidity-ramp protocols‡‡										
Ravanelli and colleagues (2015)[47]	8	No female participants, eight male participants	24	120	36°C; 42°C	28% to 91%; 22% to 67%	23 (7); 38 (13)	14 (14); 23 (8)	–9 (–15 to –3)¶; –15 (–26 to –4)¶	39%
Gagnon and colleagues (2017)[48]	9	Four female participants, five male participants	26	100	42°C	30% to 70%	44 (14)	34 (12)	–10 (–21 to 1)¶	23%
Gagnon and colleagues (2016)[49]	9	Six female participants, three male participants	68	100	42°C	30% to 70%	26 (16)	27 (19)	1 (–12 to 14)	··

Data are mean (SD) or mean (95% CI) as provided in the studies or approximated in analyses. Data were extracted from text and tables directly or from figures via freely available software (appendix pp 59–60).[44] bpm=beats per min. *Ambient conditions expressed as absolute air temperature and relative humidity. †Change in heart rate calculated as the change from baseline to the last measured timepoint during exposure. ‡Effectiveness of fans *vs* direct ambient cooling (eg, air conditioning) was established for studies in which fan use reduced heart rate. This measure was calculated as the point estimate for fan-induced reduction in heart rate divided by the point estimate for the increase in heart rate during exposure without fan use, which would have been prevented if the person was exposed to ambient cooling sufficient to maintain a thermoneutral environment (approximately 22–24°C). §Heat-event simulation studies were those in which resting participants were exposed to stable environmental conditions reflective of historical extreme heat events. ¶Point estimate indicated that fan use was beneficial, defined as ≥5 bpm reduction in heart rate with fan use.[37] ‖95% CI indicated that fan use was detrimental (ie, 5 bpm not included within the CI). **In the fan condition, people were allowed to apply water to the skin ad libitum (in Morris) or the shirt of the participants was soaked with water (in Cramer and colleagues). Combined fan and supplemental skin or cloth wetting were compared with no cooling intervention (ie, dry shirt and no fan). ††Point estimate indicated that fan use was detrimental, defined as ≥5 bpm reduction in heart rate with fan use.[37] ‡‡In humidity-ramp studies, participants were first exposed to increased air temperatures with low relative humidity. Humidity was then increased every 2 min to 5 min.

Table 2: **Laboratory-based studies of the effectiveness of pedestal fans in reducing heart rate in resting people**

conditioning by increasing the air temperature limit for thermal comfort by 3–4°C (although the comfort limits technically assumed that no mechanical cooling was available).[55] Although this strategy is viable for limiting the economic and environmental effects of direct cooling, improving thermal comfort does not necessarily translate into reduced physiological strain. Their model suggested that in some areas of Australia (the focus of the study) and in many of the hottest countries (eg, India and Kuwait), summer indoor temperatures approaching or exceeding 35°C would be considered comfortable with fan use.[55] Even with a fan, individuals will probably have considerable hyperthermia at these increased air temperatures (figures 1, 4).

Fans might therefore contribute to a false sense of security and prevent individuals from engaging in more powerful cooling behaviours, such as reducing the air conditioning set point or visiting a cooling centre.[9,35,77] This consideration is especially pertinent for older adults, many of whom have a diminished ability to sense their own thermal state.[32,78] The complex relations between fan use, thermal comfort and strain, and behavioural thermoregulation require further scrutiny. However, some evidence supports a potentially concerning so-called masking effect of fans on thermal strain. Laboratory-based studies have reported that fan use elicited a clinically meaningful improvement in thermal comfort without a meaningful reduction in core temperature in young adults[37] and increased core temperature without altering thermal comfort in older adults.[48]

The importance and sustainable use of ambient cooling

Our analyses estimated that electric fans are, at most, 36% as effective as air conditioning for reducing core temperature in healthy older adults at ambient air temperatures of 30°C or more (figure 1). The relative ineffectiveness of fans is a natural consequence of the negative feedback organisation of the human thermoregulatory system—core temperature provides the primary stimulus for sweat production and needs to be increased if sweating is required for heat loss.[24,79] Interventions relying on facilitating sweat evaporation (eg, fans) cannot prevent core temperature increases as effectively as those circumventing the need for the evaporative cooling mechanisms of the body.

Air conditioning provides highly effective ambient cooling, but current applications are energy-intensive and can be environmentally damaging.[12,13,15] The sustainability of air conditioning therefore depends on whether its environmental and financial costs can be ameliorated. Building-level and person-level interventions to supplement, rather than replace, air conditioning are a potential

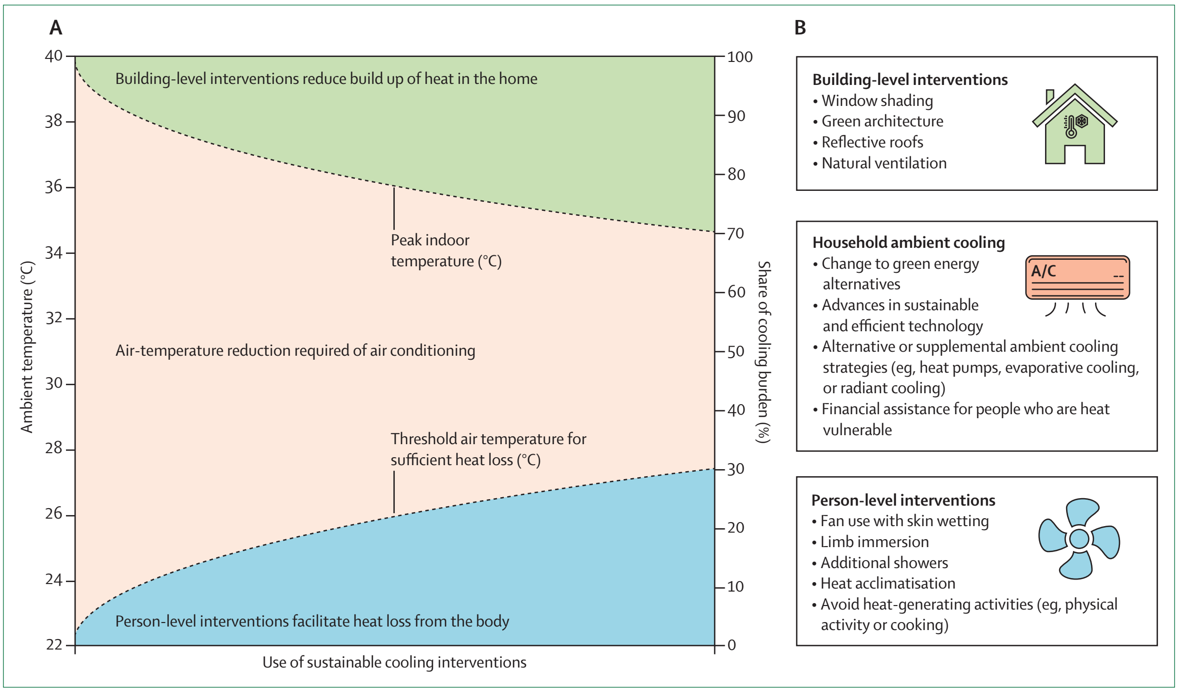
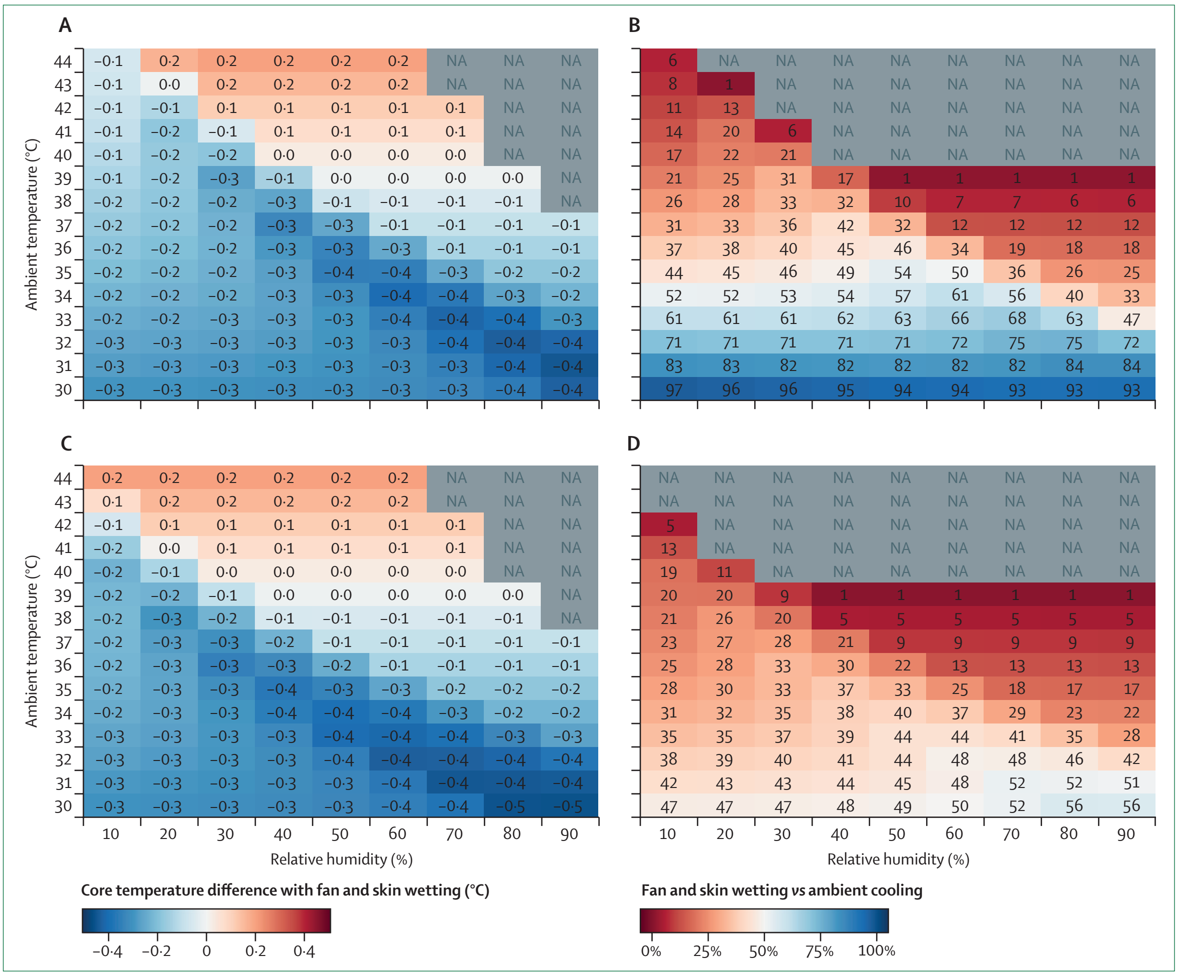


***Figure 5:* Use of sustainable cooling interventions to reduce reliance on air conditioning**
The figure depicts air temperature in a hypothetical domicile. The peak temperature without the use of cooling interventions is 40°C, which is similar to indoor temperatures that were measured during the summer 2021 Pacific northwest heat-dome event.[2] Building-level interventions can be used to prevent the build-up of heat within the home, reducing peak temperatures (green shaded area).[80–83] Person-level interventions can raise the crucial air temperature at which sufficient body-environment heat exchange to maintain core temperature at basal or near-basal levels can occur (blue shaded area).[16] The net result is that the cooling requirement of air conditioning (red shaded area) is attenuated without sacrificing protection for vulnerable occupants. The environmental and financial costs of air conditioning can be further ameliorated with transition to sustainable energy alternatives (eg, solar, wind, or nuclear), improvements in cooling technology, use of less energy-intensive ambient cooling strategies (eg, evaporative coolers, misting fans, or radiant coolers), and financial-assistance programmes.[10–15]

solution to this problem (figure 5).[15,80] For example, shading through tree planting or installation of external window shutters, reflective roofs, and green architecture can be used to prevent build-up of heat in populated areas, reducing the requirement for ambient cooling.[80–83] Building-level strategies can be implemented alongside interventions to facilitate body–environment heat exchange,[16] increasing the threshold air temperature at which sufficient skin–environment heat transfer can occur. Such person-level interventions could include fan use, which is more effective at low temperatures (figures 1, 4). Combining fans with skin-dousing is another promising option (figure 6),[25] although empirical support for its effectiveness is needed (appendix p 33).

Interventions that aim to facilitate heat-acclimatisation can also be used to reduce reliance on air conditioning.[84] Regular heat exposure has long been known to improve physiological responses to heat stress.[65–67] Maintaining or increasing physical activity when ambient temperatures begin to increase in the spring and early summer, or purposefully exposing oneself to high-heat conditions (eg, sauna or hot-water bathing), are therefore low-cost and sustainable methods for improving personal heat resilience and confer numerous additional health benefits (although a certified medical professional should be consulted before engaging in any new exercise or heat-exposure programmes).[85–87] However, humans have restricted capacity to adapt to increased temperatures.[65] Acclimatisation is therefore unlikely to provide full protection from extreme heatwaves, especially early in the heat season.[88] In these cases, powerful cooling strategies will still be required, but any acquired resilience will mean that individuals will be able to remain safe and comfortable in increased air temperatures, reducing the requirement for direct cooling (figure 5).

Sustainable air conditioning can also be realised through technological advances and policy initiatives. Global shifts from fossil fuels to green alternatives (eg, wind, solar, or nuclear), efficient cooling technologies, and reductions in the use of environmentally harmful refrigerants (eg, hydrofluorocarbons) are expected to lead to attenuations in air conditioning-related emissions.[12–15] For example, more stringent performance standards for air conditioners have been estimated to reduce the increase in air conditioning-related electricity demands by approximately 67% globally (1410 TWh by 2050 compared with 4210 TWh in the baseline scenario).[12] Similarly, proposed amendments to the Montreal Protocol[89] to reduce and eliminate hydrofluorocarbon use could prevent up to 0·4°C of global warming by 2100.[13,14] A report by the UN indicated that these strategies, in



A

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	−0·1	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
43	−0·1	0·0	0·2	0·2	0·2	0·2	NA	NA	NA
42	−0·1	−0·1	0·1	0·1	0·1	0·1	0·1	NA	NA
41	−0·1	−0·2	−0·1	0·1	0·1	0·1	0·1	NA	NA
40	−0·1	−0·2	−0·2	0·0	0·0	0·0	0·0	NA	NA
39	−0·1	−0·2	−0·3	−0·1	0·0	0·0	0·0	0·0	NA
38	−0·2	−0·2	−0·2	−0·3	−0·1	−0·1	−0·1	−0·1	NA
37	−0·2	−0·2	−0·2	−0·3	−0·3	−0·1	−0·1	−0·1	−0·1
36	−0·2	−0·2	−0·2	−0·3	−0·3	−0·3	−0·1	−0·1	−0·1
35	−0·2	−0·2	−0·2	−0·3	−0·4	−0·4	−0·3	−0·2	−0·2
34	−0·2	−0·2	−0·2	−0·3	−0·3	−0·4	−0·4	−0·3	−0·2
33	−0·2	−0·2	−0·3	−0·3	−0·3	−0·4	−0·4	−0·4	−0·3
32	−0·3	−0·3	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4	−0·4
31	−0·3	−0·3	−0·3	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4
30	−0·3	−0·3	−0·3	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4

B

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	6	NA	NA	NA	NA	NA	NA	NA	NA
43	8	1	NA	NA	NA	NA	NA	NA	NA
42	11	13	NA	NA	NA	NA	NA	NA	NA
41	14	20	6	NA	NA	NA	NA	NA	NA
40	17	22	21	NA	NA	NA	NA	NA	NA
39	21	25	31	17	1	1	1	1	1
38	26	28	33	32	10	7	7	6	6
37	31	33	36	42	32	12	12	12	12
36	37	38	40	45	46	34	19	18	18
35	44	45	46	49	54	50	36	26	25
34	52	52	53	54	57	61	56	40	33
33	61	61	61	62	63	66	68	63	47
32	71	71	71	71	71	72	75	75	72
31	83	83	82	82	82	82	82	84	84
30	97	96	96	95	94	94	93	93	93

C

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	0·2	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
43	0·1	0·2	0·2	0·2	0·2	0·2	NA	NA	NA
42	−0·1	0·1	0·1	0·1	0·1	0·1	0·1	NA	NA
41	−0·2	0·0	0·1	0·1	0·1	0·1	0·1	NA	NA
40	−0·2	−0·1	0·0	0·0	0·0	0·0	0·0	NA	NA
39	−0·2	−0·2	−0·1	0·0	0·0	0·0	0·0	0·0	NA
38	−0·2	−0·3	−0·2	−0·1	−0·1	−0·1	−0·1	−0·1	NA
37	−0·2	−0·3	−0·3	−0·2	−0·1	−0·1	−0·1	−0·1	−0·1
36	−0·2	−0·3	−0·3	−0·3	−0·2	−0·1	−0·1	−0·1	−0·1
35	−0·2	−0·3	−0·3	−0·4	−0·3	−0·3	−0·2	−0·2	−0·2
34	−0·2	−0·3	−0·3	−0·4	−0·4	−0·4	−0·3	−0·2	−0·2
33	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4	−0·4	−0·3	−0·3
32	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4	−0·4	−0·4	−0·4
31	−0·3	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4	−0·4	−0·4
30	−0·3	−0·3	−0·3	−0·3	−0·3	−0·4	−0·4	−0·5	−0·5

D

Ambient temperature (°C)	10	20	30	40	50	60	70	80	90
44	NA	NA	NA	NA	NA	NA	NA	NA	NA
43	NA	NA	NA	NA	NA	NA	NA	NA	NA
42	5	NA	NA	NA	NA	NA	NA	NA	NA
41	13	NA	NA	NA	NA	NA	NA	NA	NA
40	19	11	NA	NA	NA	NA	NA	NA	NA
39	20	20	9	1	1	1	1	1	1
38	21	26	20	5	5	5	5	5	5
37	23	27	28	21	9	9	9	9	9
36	25	28	33	30	22	13	13	13	13
35	28	30	33	37	33	25	18	17	17
34	31	32	35	38	40	37	29	23	22
33	35	35	37	39	44	44	41	35	28
32	38	39	40	41	44	48	48	46	42
31	42	43	43	44	45	48	52	52	51
30	47	47	47	48	49	50	52	56	56

***Figure 6:* Estimated effect of fan use and skin wetting on resting core temperature**

(A) Estimated difference in core temperature for a young adult (aged 18–40 years) with use of a fan generating an air velocity of 4·5 m/s at the front of the body from 1 m away combined with skin wetting, calculated as the core temperature estimated in the fan and skin-wetting model minus that in the no fan and no skin-wetting model. Individuals were assumed to be resting in the seated position and applying approximately 116 mL of water over the skin surface every hour. The model also assumed that airflow was being generated evenly across the front surface of the body. (B) Estimated effectiveness of fan use and skin wetting relative to direct ambient cooling (eg, air conditioning) sufficient to maintain a thermoneutral ambient environment (approximately 22–24°C) in a young adult, calculated as the reduction in core temperature with fan use and skin wetting divided by the core temperature change in the no-fan model. (C, D) Estimated change in core temperature and effectiveness of fans and skin wetting for a hypothetical older adult (aged 65 years or older) via the same methods as described for a young adult. Data were generated via the simplified heat balance model. The relationship between the required sweat rate and resting core temperature used in this model was adjusted for supplemental skin wetting according to the approach by Hospers and colleagues (appendix p 33).[3] NA=not applicable.

combination with increased use of passive building-level cooling, could ameliorate as much as 96% of the greenhouse gas emissions expected to occur due to global expansion of air conditioning and other forms of cooling, such as refrigeration, between 2022 and 2050.[15]

Although efficient cooling technology should also help to reduce operational costs, public-assistance programmes can be modified to ensure improved access to adequate cooling for vulnerable communities.[10,11] Use of cooling centres is another easily implementable strategy for providing air conditioning to people without the means to operate home units,[90] and its effectiveness is supported by epidemiological and laboratory-based studies.[9,35,77] However, cooling centres are infrequently visited by the most vulnerable people during heatwaves; reducing barriers to their use and educating vulnerable groups on the dangers of extreme heat are needed to improve their viability as a cooling intervention.[90] Furthermore, brief ambient cooling probably provides little protection after a return to a hot environment,[35,77] meaning that cooling centres do not negate the need for home-based cooling strategies.

Until now, we have focused on air conditioning due to its effectiveness and the fact that it is commonly featured as a reference point in guidance documents.[8,9,16,30,39] However, even with the strategies summarised in this section, home air conditioning is unlikely to be accessible or feasible for many vulnerable people, including those in low-income and middle-income countries and approximately 1 billion individuals currently living in urban slums and informal settlements.[91] Strategies that aim to reduce ambient temperature through extraction of latent heat, such as misting fans or evaporative coolers, are promising and inexpensive alternatives to air conditioning.[16] Evaporative coolers can reduce ambient temperatures by 10–15°C,[16] corresponding to an approximate 0·5–1·0°C reduction in core temperature (figure 1). However, these strategies have their own challenges; they require a renewable water source and cooling potential is reduced in humid conditions. Furthermore, empirical evidence is required to substantiate their effectiveness for limiting physiological strain and protecting wellbeing in vulnerable populations.

Protecting heat-vulnerable populations is a daunting task and one that will require an array of solutions. Although there has been encouraging collaboration among key stakeholders across various fields (eg, public health and policy, epidemiology, urban planning, and physiology), the importance of air conditioning has been largely discounted.[16,34] Due to their effectiveness, especially for heat-vulnerable populations, we feel that air conditioning and alternative ambient cooling strategies will be crucial in efforts to bolster global resilience to extreme heat. Improving access and sustainability are crucial aims for climate adaptation.

Conclusion

Available evidence does not support recommendations that electric fans are an effective personal cooling intervention when ambient air temperature exceeds 35°C. Health agencies should continue to advise against the use of fans in very hot conditions, especially for individuals with reduced physiological capacity to respond to temperature extremes. Increased access to ambient cooling, supplemented by building-level interventions to reduce indoor heat build-up and developments to minimise the economic and environmental burdens of air condition, is crucial for improving adaptive capacity and reducing global susceptibility to hot weather and heatwaves.

Contributors

RDM, SRN, and GPK conceived and designed the report. RDM did the literature searches. RDM and NVK extracted data. RDM conducted analyses, prepared the figures, and drafted the manuscript and appendix. GPK acquired funding and was responsible for project administration. All authors revised the manuscript, approved the final version, had full access to all the data in the study, accessed and verified the underlying data, and had final responsibility for the decision to submit for publication.

Declaration of interests

GPK and RDM receive funding from the Canadian Institutes of Health Research and Health Canada. SRN receives funding from the Canadian Institutes of Health Research. NVK declares no competing interests.

Data sharing

The data and code used in our analyses are available with publication from the corresponding author (gkenny@uottawa.ca). Code and data will be shared after approval of a proposal, with a signed data access agreement.

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