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Heat-coping strategies and bedroom thermal satisfaction in New York City

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Abstract

There has been little research into the thermal condition of the sleeping environment. Even less well documented and understood is how the sleeping thermal environment is affected by occupant behaviors such as the use of air-conditioning (AC) and electric fans, or window operations. In this paper we present results from a questionnaire survey administered to assess summertime bedroom thermal satisfaction and heat-coping strategies among New York City (NYC) residents. Specifically, we investigated current AC usage in bedrooms and examined alternate cooling strategies, cooling appliance usage patterns, and the motivations that drove these patterns during the 2015 summer.

Among survey respondents (n=706), AC was the preferred heat-coping strategy, and for 30% of respondents was the only strategy used. Electric fan use and window opening were deemed ineffective for cooling by many respondents. Indeed, less than a quarter of all respondents ever opened windows to alleviate heat in their bedrooms. In general, people utilized strategies that modify the environment more than the individual person. Unsurprisingly, the frequency and overall use of AC were significantly associated with greater bedroom thermal satisfaction; however, setting AC to a lower temperature provided no additional benefit. In contrast, more frequent use of electric fans was associated with lower thermal satisfaction. In addition, 14.7% of all respondents did not have AC in their sleeping environment and 5.8% were without any AC at home. Despite the high penetration of AC ownership, usage cost was still a major concern for most.

This work contributes to a better understanding of bedtime heat-coping strategies, cooling appliance usage patterns, and associated thermal satisfaction in NYC. The findings of this study suggest resident AC usage patterns may not be optimized for thermal satisfaction. Potential

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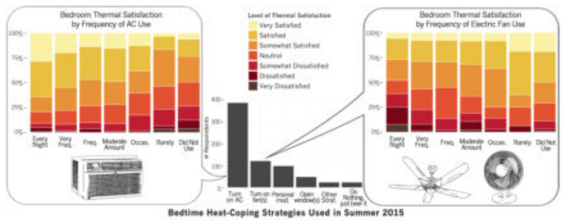
alternative cooling approaches could be explored to better balance maximizing thermal comfort while reducing energy consumption and environmental impact.

Graphical abstract



Keywords

thermal comfort; questionnaire survey; air conditioner; electric fan; windows; sleeping environment

1. Introduction

Hot weather events are expected to increase and intensify during the 21st century as the climate changes and the planet warms. Populations in large urban environments such as New York City are at particular risk as urban heat island (UHI) effects will further amplify temperatures in these localities. Urban residents also spend most of their time indoors, and the majority of that indoor time is spent in the home environment. In fact, in the US it is estimated that the elderly spend up to 81% of their day at home (Klepeis et al. 2001). More than 80% of heat mortality in recent years in NYC also occurred at home (CDC 2013). It follows that the characteristics and operation of residential buildings are an important yet understudied modifier of the effect of climate on human health.

Among heat-related health impacts, sleep disturbance is of particular interest because more than half of time at home is spent sleeping. Further, increasing temperatures may strongly affect sleep because body thermoregulation is reduced during sleep (Carskadon et al. 2011; Heller et al. 1996), and a lower core body temperature is required for the onset and maintenance of sleep (Krauchi et al. 2000; van Someren et al. 2002). Many experimental human studies under laboratory conditions in the past 25 years have found that overly warm environments increase wakefulness and disturbance, and reduce sleep time (Bach et al. 2002; Haskell et al. 1981; Horne 1992; Lan et al. 2014; Schmidt-Kessen et al. 1973). Many epidemiological studies have also suggested that it may be the lack of nighttime relief from daytime heat that is particularly deleterious (e.g. Kilbourne 1997; McGeehin and Mirabelli 2001). More broadly, sleep loss can lead to many other health consequences. For instance, several cohort studies have found associations between reduced self-reported sleep duration and cardiovascular disease, all-cause mortality, as well as symptomatic diabetes (Alvarez and Ayas 2004; Strand et al. 2015). Indirectly, poor sleep is a significant predictor of road traffic accidents and contributes to decreased job performance and productivity (Philip et al. 2014; Rosekind et al. 2004).

While there is no shortage of studies on sleep and associated health impacts, there has been little research into the thermal condition of the sleeping environment, its impact on comfort, sleep quality, and wellbeing. Even less well documented and understood is how the sleeping thermal environment is affected by the physical characteristics of the residence and bedroom, and by occupant behavior, such as the use of air-conditioning (AC) and electric fans, as well as window operations.

In the US, residential AC use is common and widely accepted as a routine heat-coping strategy during summer. Indeed, many studies have shown AC use to be a protective factor against heat-related mortality (Naughton et al. 2002; O'Neil et al. 2005; Semenza et al. 1996) and heat-related hospital admissions (Ostro et al. 2010). Governmental agencies and weather service organizations worldwide commonly advise the use of AC at home or air-conditioned public spaces as a means of reducing heat-related morbidity (Hajat et al. 2010).

While AC use is a logical protective measure against heat-related health impacts, reliance on AC is inherently problematic because its use is energy intensive and can create disproportionate impacts at peak load times and cause blackouts, such as during heat waves when AC is most needed. AC use also contributes to global warming and the UHI effect, which further exacerbates the need for AC.

It was estimated in 2009 that 87% of US households were equipped with air conditioning (US EIA 2011). In spite of the high penetration of ownership in the US, little is documented on AC usage patterns and the motivation for those patterns. Indeed, while it may appear logical to assume that AC usage is mainly driven by temperature and the cost of operation, existing studies reveal a more complicated set of drivers. For instance, in a Hong Kong survey study of AC use in bedrooms, Lin and Deng (2006) found that even when operating AC at night, a quarter of the 554 surveyed subjects still found it too hot while another quarter found it too cold. In a Japanese survey study, Kayaba et al. (2014) also found that at least some people opt to open their windows to alleviate heat even when they have AC at their disposal. These prior findings suggest that AC usage may not be invariably preferred or even effective. Given the electrical demand from residential AC and its impact on the environment, it is necessary to understand how residents use AC to cope with heat.

Here we present results from a questionnaire survey administered to assess summertime bedroom thermal satisfaction and heat-coping strategies among New York City (NYC) residents. We used this questionnaire to investigate current AC usage in NYC bedrooms and to examine alternate cooling strategies, cooling appliance usage patterns, and the motivations that drive these patterns. We hypothesized: 1) bedroom thermal satisfaction would be highly correlated with AC use; 2) alternate heat-coping strategies would be used to lighten the financial burden and environmental concerns of AC use; and 3) AC usage patterns would be highly variable among residents.

2. Material and methods

2.1. Study area and distribution

Over 25,000 invitations to participate in our online anonymous questionnaire survey were distributed to NYC (all 5 boroughs) adult residents at the end of September 2015 via Qualtrics, a research firm. Responses were collected from Sept. 22 – Oct. 27. During this period 3884 surveys were attempted and 706 validated surveys were collected. 60% of these 706 were obtained during September, 82% by the end of the first week of October, and 95% by the end of the second week.

2.2. Target subjects, questionnaire design, and quality assurance techniques

Questions in the survey were designed to gather information on respondents' sleeping thermal satisfaction and heat-coping strategies during the 2015 summer. Demographic information, self-reported health status, as well as the characteristics of respondents' residence and bedroom were also collected. The electronic format allowed skip- and display-logic, choice randomization, and content and format validation techniques to be built into the survey. These features enabled in-depth yet efficient and clear survey flow by hiding inapplicable questions and displaying follow-up questions based on participants' responses. Many questions are semi-open ended such that the respondents could write in their own answers if none of the provided choices were suitable. The survey was designed to be completed in 15–25 minutes, depending on respondent survey flow.

The survey has several initial screening questions to ensure only respondents who were 18 or over, had spent summer 2015 in NYC, had a good understanding of English, and did not work nightshifts (i.e. were at home at night) could continue. Quality control questions, such as attention filters, reverse wording and logic pairing, were also embedded throughout the questionnaire to ensure that respondents were completing the survey in earnest. Surveys that were completed too quickly or slowly were also discarded. This second layer of screening yielded the final 706 validated surveys, which serve as the basis for the present study. No personally identifiable information was collected, and the study protocol was deemed exemptible by the Columbia University Institutional Review Board

2.3. Outdoor data

Quality Controlled Local Climatological Data (QCLCD) were downloaded from the National Centers for Environmental Information (NCEI) (2016). Hourly air temperature and relative humidity data for the three weather stations in NYC: Central Park, JFK and La Guardia Airports were averaged to create one "NYC" set of weather data.

2.4. Statistical analyses

The sample size of 706 is reasonable with respect to NYC's population of 8.5 million for the present study because this proportion, albeit small, is similar to that in other studies in existing literature. For instance, Lin and Deng (2006) used a sample size of 554 valid surveys from adults 18+ for a population of 6.9 millions in Hong Kong (during 2006). A 2011 telephone survey of extreme heat awareness and protective behaviors conducted by the

Department of Health and Mental Hygiene (DOHMH) of NYC in late September 2011 also had 719 adults age 18+ (Lane et al. 2013).

Most survey variables are either categorical or ordinal. Non-parametric methods are employed for analyses, including Pearson's Chi-square test, the Kruskal-Wallis test (analogous to a one-way independent ANOVA) with *post-hoc* pairwise comparisons, and the Mann-Whitney U-test (aka Wilcoxon rank-sum test). The Kruskal-Wallis test is used with one independent variable of two or more levels and an ordinal dependent variable, such as the level of bedroom thermal satisfaction measured on a 7-point Likert scale, which we treat as ordinal, not interval. For other, interval variables we used a range of non-parametric correlation methods, including robust Goodman-Kruskal gamma and Gaussian rank correlations with fuzzy ordering (Bodenhofer et al. 2012), and bootstrapped Spearman's rho and Kendall's tau.

3. Results

3.1. Summer 2015

Summer 2015 in NYC was not exceptionally hot (Figure 1); only two Heat Advisories were issued, both during July. In NYC, a Heat Advisory is issued when "the Heat Index[1] is *forecast* to reach 95–99°F for at least 2 consecutive days or 100 to 104°F for any length of time" (NWS 2016a).

3.2. Respondent characteristics and time at home

Demographic characteristics of the 706 validated surveys are described in Supplemental Material (SM) Table S1. The sample matched well with the NYC general population for gender and age structure but was more white, slightly more affluent, more educated, and included more home owners and bigger homes. Manhattan and two-person households were also overrepresented. Nevertheless, the sample included mostly long-term NYC residents, with three quarters (n=532) having lived 10+ years (and 66% 15+ years) in NYC. 418 (59.2%) of the respondents lived in apartments, 52 of which were studios (no separate bedrooms). Respondents in studio apartments were instructed to answer questions about their studios instead of bedrooms. Subsequent analyses include data from studio residences unless otherwise noted.

The median number of hours spent at home was 14 and most of these hours were spent at night and in the bedroom (Mdn=9.5). Respondents 65+ spent even more time at home (Mdn=18), but slightly less time in the bedroom (Mdn=9) (details see SM Table S2).

3.3. Most commonly used heat-coping strategies

Although the summer of 2015 was not exceptionally hot for NYC, 72.9% of all respondents reported "turning on AC (cooling)" as a strategy for coping with heat at night. Only 40.4% selected "turning on fans", and 23.5% selected "opening windows" (Figure 2).

[1]The Heat Index is an estimate of perceived temperature given both relative humidity and air temperature. The Heat Index is calculated according to the algorithm published by the US National Weather Service (NWS 2016b).

While the majority (60.0%, n=423) of all respondents employed two or more strategies to cope with heat, almost half of that majority (n=180) still chose to use AC the most (red portions in Figure 2). Furthermore, 30.0% (n=212) of all respondents reported AC as the *only* strategy they used (brown portions). Only 17.6% of all respondents (n=124) indicated “turning on fan(s)” and 6.9% (n=49) indicated “opening windows” as their most used or only strategy. No respondent chose “wearing less clothes to sleep” as their sole heat-coping strategy; however, more respondents used this strategy than “opening windows”.

Although a range of heat-coping strategies have been identified, as Figure 2 illustrates, those that modify the environment were more commonly used and preferred than those that modify the person (e.g. wearing less clothes, cold drinks). Because the majority of respondents employed more than one coping strategy, invariably many people may have made personal adjustments alongside environmental modifications, especially because very few respondents indicated they relied *only* on personal adjustments. The concomitance and interactions of these two types of heat-coping strategies will be addressed in a separate paper. The remainder of the present work will focus on three environment-modifying heat-coping strategies: (1) turning on AC (cooling function), (2) turning on electric fan(s); and (3) opening windows. Only 44 respondents out of all 706 did not employ any environment-modifying strategies. 44.8% (n=316) of all respondents employed at least two environment-modifying strategies. The top combinations were: AC (cooling) and electric fans; and electric fans and opening windows. The fan-only function of AC was not further analyzed because only 10 respondents noted it as their most utilized heat-coping strategy in the bedroom at night. AC (cooling) will simply be referred to as AC henceforth.

3.4. Factors influencing heat-coping strategy choice

While turning on AC was the most utilized heat-coping strategy during summer 2015, 10.0% (n=63) of the respondents who had AC installed in their bedroom (n=602) chose not to use it at night, most commonly because it was “not hot enough” or “expensive to run” AC (yellow bars in Figure 3.1). Electricity cost was also the most cited reason for not having an AC in the bedroom (brown bars in Figure 3.1).

Among respondents who used AC (for either cooling or fan function) (n=539), almost half (48.4%) noted electricity cost as a downside of using AC (Figure 3.2). Only 9.1% of AC users selected “bad for the environment” as a negative aspect of AC use, which was also a low-priority reason among respondents who did not have AC or did not use an installed AC in the bedroom (Figure 3.1).

Respondents avoided “turning on fans” and “opening windows” mostly because they doubted the efficacy of these strategies (Figure 3.4–5). The logistical and practical concerns of opening windows such as noise and insects were also deterrents but security and privacy were less of an issue (Figure 3.5–7). Finally, far more AC users had no complaints about AC use (148 of 539) than respondents who opened windows to cool (1 of 166) (“no downside” in Figure 3.2 and Figure 3.6).

We also asked the respondents who had AC in their households (n=665) to identify additional purposes of using an AC in the bedroom at night other than to cool. While 44.2%

of respondents indicated that they did not use AC for other reasons, the majority (55.8%) indicated at least one other purpose in addition to cooling (Figure 3.3).

3.5. Usage patterns of chosen heat-coping strategies

3.5.1. Air conditioning—The majority of respondents who had AC in their sleeping environment (70.9%, n=427) had the window/wall unit type (Table 1). A larger proportion of respondents who lived in houses (26.7%) had a central/split system AC than those who lived in apartments (16.7%); and more apartment residents had window/wall unit AC (63.9%) than those who lived in houses (55.6%). However, the proportion of respondents who did not have AC in the bedroom was the same for both residence types (15%).

While a great majority of all respondents (85.2%) had AC in their bedrooms, only 66.6% of this subset indicated that their AC could be set to a specific temperature. The median set temperature was 70°F (21.1°C) (average ± SD: 20.6±2.9°C or 69±5.2°F) and the median daily number of hours of AC use in the bedroom at night was 8 hours (average ± SD: 10.3±6).

We did not find the AC set temperature to differ by AC type. However, the income distribution of respondents who had window/wall unit AC was significantly different from those who had central/split AC ($\chi^2(4)= 23.98$, $p<.0001$). Specifically, the odds of having an annual combined income of $50k+ was 3.3 (OR, CI_{95} 1.9, 5.9) times higher for those with central/split system AC than those who had window/wall unit AC. Respondents who lived in houses and owned their homes were also more likely to have central/split system AC ($\chi^2(1)=10.45$, $p<.01$; $\chi^2(1)=30.59$, $p<.0001$; respectively).

Because the temperature and therefore the need to cool varied throughout the summer, we asked the respondents how frequently over the entire season they turned on AC. We also asked the respondents to identify the typical time of the day when they first turned on the AC in their bedroom and how long they kept the AC running. Using the answers to these two questions we identified six distinct time periods of AC use. The breakdown by frequency and time period of AC use are listed in Table 2.

47.0% of the respondents who used AC for cooling had done so either every night or very frequently (~90% of the nights) over the entire summer. Half (50.1%) of that 47.0% also indicated that when they did have the AC on, they kept it running almost at all times. This means that nearly one quarter (23.8%) of respondents who utilized AC as a heat-coping strategy kept the AC running all day and all night throughout almost the entire summer. These “overtime” AC users, however, were no different from other AC users in terms of the amount of time they spent at home or in their bedrooms, or in terms of their age, gender, employment status, highest education attainment, income level, housing tenure status, residence type, or whether they were responsible for the AC electricity bill (based on Pearson’s Chi-square and Kruskal-Wallis tests, see SM Table S3).

In addition to income, we asked respondents whether the cost of having and running an AC unit was a barrier to using AC as a heat-coping strategy in the sleeping environment at night. This variable, “financial burden of AC use”, is a better measure of any income-driven AC disparity because this variable accounts for, at least to some extent, the priority that the respondents placed on AC cooling with respect to their day-to-day expenditures and budget. Accordingly, we observed that the "overtime" AC users were more likely to have less financial burden from AC use compared to other AC users (W=20320, r=.11, p<.05).

A small proportion of all respondents (n=91) selected both "turning on AC (cooling) and "opening windows" as heat-coping strategies. While the majority of this subset indicated that they *never* opened windows while the AC was running, several respondents did use both strategies concurrently. The most common reasons were to "ventilate/circulate the air in the room" (n=16), "to let in fresh sir" (n=13), and to prevent the room from getting too cold from AC use (n=7). Furthermore, 20.9% of the respondents who used AC to cool indicated that they had at least sometimes used an electric fan at the same time as well.

Overall, 14.7% (n=104) of all respondents did not have AC installed in their sleeping environment (including both studios and bedrooms) and 5.8% (n=41) of all respondents did not have any AC (installed or not) in any part of their homes.

3.5.2. Electric fans—Overall, ceiling fan was the most common type of fan owned by respondents who used fans as a way to alleviate heat. About a quarter (25.4%) of those with *only one* fan had ceiling fans; nearly another quarter (23.9%) had small portable/table fans. In addition, the vast majority (72.5%) of fan users preferred to place the fans close to them in order to feel the air flow.

Analogous to disparities of AC type, the income distribution of respondents who had ceiling fans was significantly different from those who had other types of fans (χ^2(4)= 13.81, p<. 05). Specifically, the odds of having an annual combined income of $75k+ was 2.4 (OR, CI_{95} 1.4, 4.1) times higher for those with a ceiling fan than respondents who used other fan types. Respondents who lived in houses and owned their homes were also more likely to have ceiling fan (χ^2(1)= 22.20, p<.0001; χ^2(1)= 28.95, p<.0001; respectively).

46.0% of respondents who used electric fans for cooling indicated that they used them either every night or very frequently (~90% of the nights) over the entire summer. 61.7% of that 46.0% also indicated that they kept the fans running almost at all times. This means that over a quarter (28.4%) of the respondents who had utilized electric fans as a heat-coping strategy had kept the fans running all day and all night throughout almost the entire summer. These "overtime" fan users, however, were no different from other fan users in terms of the amount of time they spent at home or in their bedrooms, or their age, gender, employment status, highest education attainment, income level, financial burden of AC use, housing tenure status, residence type, or AC electricity bill responsibility (based on Pearson's Chi-square and Kruskal-Wallis tests, see SM Table S3).

3.5.3. Window operation—While it is illegal to have a bedroom without provision of light and natural ventilation in New York City (NYC Administrative Code § 27–746, −2058), 2.8% (n=20) of all respondents reported not having any glazed facades (i.e. walls with windows or glass doors) in their sleeping environment. Of the remaining 686 respondents who had glazed facades, 5.2% (n=36) noted that their windows were either fixed or stuck.

The majority (53.1%) of the respondents who opened windows to cope with heat in their bedroom at night typically left the windows open at all times (Table 1); 28.3% left the windows open at least throughout the night. 17 respondents noted that they only opened the windows prior to bedtime and *closed* them when going to sleep. All but four of these respondents then turned on AC and used it until the middle of or throughout the night.

Significantly more respondents who did not use or have AC in their bedrooms opened windows to alleviate heat $\chi^2(1)$=36.01, p<.0001, OR=3.09 (CI_{95} 2.07, 4.58). In addition, significantly more respondents who had window/wall unit AC also chose "opening windows" as a heat-coping strategy than respondents who had central/split AC $\chi^2(1)$=13.02, p<.001, OR=2.96 (CI_{95} 1.58, 5.97).

3.6. Bedroom thermal satisfaction

The field of thermal comfort research is primarily based on short-term assessments (e.g. hourly or sub-daily). In our study, because respondents were asked of their experiences and behaviors with respect to the entire summer, the term "thermal satisfaction" in lieu of "thermal comfort" was used specifically to imply a heuristic averaging over a longer period of time, which may comprise a mixture of days or moments of comfort and discomfort.

On the whole, our survey found that 42.8% (n=302) of all respondents were satisfied or very satisfied with their sleeping thermal environment in summer 2015. A mere 5.7% (n=40) said they were dissatisfied or very dissatisfied. We next present whether any usage patterns of respondents' chosen heat-coping strategies were associated with their satisfaction with the bedroom thermal environment.

3.6.1. Correlation with outdoor conditions—In addition to the satisfaction over the entire summer, respondents were also asked of their satisfaction with respect to just the month prior to taking the survey. We used the latter to explore potential associations with outdoor meteorological variables, including average maximum/mean/minimum air temperature and Heat Index (HI) of both the month prior and the week prior to the date of survey completion. Because the entire survey campaign was completed in one month, we did not have large variations of outdoor conditions (e.g. month prior maximum temperature: 24.0±3.1°F; HI:79.5±8.9°F). As a result we found very weak associations in general. Nevertheless, correlations were higher and more significant with minimum (than with maximum and mean) temperature and HI during the prior month, and with maximum (than with minimum and mean) temperature and HI during the prior week (see Figure S1 in SM). Further research especially monitoring studies are required to investigate these potential trends further.

3.6.2. Effects of demographic, socioeconomic, personal, and housing characteristics—In terms of demographic and socioeconomic factors, we did not find gender, education level or race to make a difference in respondents' bedroom thermal satisfaction. Although this could be affected by the fact that respondents were on average more educated and more white than the general NYC adult population. However, being 65 or older, a homeowner, and especially being retired were all significantly associated with higher levels of satisfaction (Figure 4). Higher income was also correlated with being more satisfied, but a much larger (negative) effect was observed for “financial burden of AC” than for income alone.

In terms of personal factors, we did not find Body Mass Index (BMI) to make a difference in respondents’ thermal satisfaction (Figure 4). However, better self-reported physical health and especially higher quality of life were both associated with greater satisfaction. Being acclimatized to NYC summer was also correlated with greater satisfaction, albeit to a smaller extent.

In terms of residence characteristics, living in a house was associated with higher bedroom thermal satisfaction. Because only 18.4% of those who lived in a house were renters (compared to 84.1% of those who lived in apartments), we looked into the difference by *residence-tenure* type, which yielded a larger effect size with house-owners being significantly more satisfied (Figure 4). Of note is that we did not find living on the top floor of an apartment building, number of bedrooms in residence, or the amount of direct sunlight in the bedroom to make a difference in satisfaction (details see SM Table S5). Again because this is a survey study, these non-associations need to be re-examined using data from monitoring research.

3.6.3. Effects of chosen heat-coping strategies—The use of AC and combined strategies involving AC were significantly associated with greater bedroom thermal satisfaction (Figure 4). Respondents who employed only one heat-coping strategy for the entire summer were more satisfied than respondents who employed multiple strategies. This finding may be due to the fact that 75% of those using only one strategy used AC.

Simplifying the satisfaction scale to satisfied, neutral, and dissatisfied, the odds a respondent was dissatisfied with his or her sleeping thermal environment was 4.1 (CI_{95} 2.5, 6.5) times higher for those who did not have or chose not to use AC this summer than those who did. A Pearson’s Chi-Square Test between those who were satisfied and dissatisfied (neutral excluded) $\chi^2(1)=40.5$ was significant at $p < 0.001$.

3.6.4. Effects of AC usage patterns—Thus far, the results have provided ample evidence that using AC made a significant difference in respondent bedroom thermal satisfaction. We investigated further whether certain aspects of usage pattern contributed to that difference (detailed statistics in SM Table S7). We did not find the usage of the energy saving function on AC units to correlate with satisfaction. However, we observed a small effect (r=.12, p<.01) among AC types: among those who had AC installed in their bedrooms this summer, respondents who had central/split system AC were more satisfied with their bedroom thermal condition than respondents who had window/wall unit AC.

No significant association between respondents’ thermal satisfaction and AC set temperature was found (see SM Figure S2). We also did not find a significant difference in the length of average daily AC use by Kruskal-Wallis test; however, non-parametric correlation analyses suggested a small effect (*r* range 0.11–0.14, all $p<.01$) that can be visualized in SM Figure S3.

While the time period of AC use did not correlate significantly with satisfaction, we observed a highly significant association ($r=.35$, $p<.0001$) with the frequency of AC use over the entire summer, with increasing frequency associated with increasing level of satisfaction. The "overtime" AC users who had the AC on almost all day and all night throughout the entire summer were observed to be significantly more satisfied with their bedroom thermal environment than other AC users; however, the effect was small ($W=20448$, $r=.11$ $p<.05$).

3.6.5. Effects of electric fan usage patterns—Contrary to AC use, which was correlated with higher thermal satisfaction, electric fan use was associated with a *lower* level of satisfaction. In fact, we found that among fan users (n=278) the more frequently the respondents used electric fan over the entire summer, the lower their bedroom thermal satisfaction ($r=.11$ $p<.01$). This negative effect was greater for the "overtime" fan users who had the fan on almost all day and all night throughout the entire summer ($r=.19$ $p<.01$). The time period or the number of fans used did not make a difference, but fan users who had ceiling fans were significantly more satisfied than those who used other types of fans ($r=.19$, $p<.01$). Finally, we did not find window operating patterns or using a dehumidifier to make a significant difference in respondents' bedroom thermal satisfaction ($H(3) = 5.46$, $p=.141$; $H(1) = 0.23$, $p=.634$, respectively).

3.6.6. Special population: 65+ and retired—In examining the association between bedroom thermal satisfaction and various demographic and socioeconomic factors (Figure 4), respondents who were 65 or older were found to have significantly greater satisfaction than younger respondents. Because the 65+ age group is often considered part of the vulnerable population in heat-related health impact studies, we investigated what characteristics might differentiate them from younger respondents. We also examined respondents who were retired, which was highly correlated with being 65 and over.

Overall, respondents who were 65+ and who were retired were no different than respondents who were younger and not retired *except* they were significantly more likely to be apartment owners and had less financial disincentive to AC use (Figure 5). They were also slightly more likely to be more acclimated to the NYC summer, have income over $100k, and to use AC than the rest of the respondents, but none of these effect sizes was comparable to or as significant as that of the financial burden of AC use. Finally, respondents who were retired were significantly more likely to have fair to poor physical health, which was associated with *lower* level of thermal satisfaction.

4. DISCUSSION

This questionnaire survey yielded a sample of 706 valid and quality-checked responses that was well matched to NYC adult population by gender and age. Responses from this sample clearly illustrated that NYC residents (who did not work nightshifts) spend the majority of their evening and nighttime hours at home. Consequently, the sleeping environment, namely the bedroom, is of particular interest for exposure studies with respect to comfort, health, and well-being.

Although the 2015 summer was not exceptionally hot, turning on AC was found to be the preferred heat-coping strategy. In contrast, electric fan use and opening windows were deemed ineffective in cooling the bedroom by many respondents. However, thermal comfort was not the only driver of the choice of cooling strategies. Noise was an issue for both AC and fan users as well as for respondents who opened windows. The need for fresh air and ventilation was also a priority concern, especially for the AC users. This is not surprising as decades of work-place studies have consistently demonstrated that air-conditioned buildings are associated with a statistically significant increase in the prevalence of headache, lethargy, and irritation to the eye, nose and throats (so-called “sick-building syndromes” symptoms) when compared to naturally ventilated buildings (Mendell and Smith 1990; Seppanen and Fisk 2002). Surprisingly, security was not a top concern. This is probably due to the fact that most windows in NYC, especially those on lower floors, have security bars or gates. The environmental impact of AC was also not considered an important issue for most respondents, which we had originally hypothesized to be one of the top incentives (besides cost) for seeking AC-alternative heat-coping strategies.

Despite AC use being the most commonplace heat-coping strategy in NYC, the data affirmed our hypothesis that AC usage pattern showed considerable variability among residents. In addition, we identified around a quarter of the AC and fan users to be “overtime” users who had kept their AC or fan on almost all day and all night throughout the entire summer. Surprisingly these “overtime” users did not differ from the other users in terms of their demographic and socioeconomic characteristics, or even the time spent at home or in the bedroom. We only found that the cost of running AC was less likely to be a financial burden for the “overtime” AC users. This finding, together with the finding that AC’s environmental impact was generally a low priority concern, suggests a need for improved public awareness of the consequences of daily actions even those as mundane as turning on AC or fans. This might be accomplished through public education programs to teach residents how best to choose and operate cooling appliances to balance achieving thermal comfort, reducing energy consumption, and minimizing environmental impact. The Department of Energy (DOE) has already set up informational webpages, such as “Spring and Summer Energy-Saving Tips” (DOE 2016) towards this effort. It may be helpful for health and weather agencies and organizations to cross-reference these links on their own websites in places where residents look up heat-illnesses prevention tips.

Next, it must be highlighted that less than a quarter of all respondents (23.5%) had ever opened windows to alleviate heat in their bedroom in 2015 summer. Natural ventilation via open windows is an economical cooling strategy yet it was employed less often than “wearing less clothes to sleep” (Figure 2). Further, 7.9% of all respondents either did not have windows or had stuck or inoperable windows in their bedrooms, thus denying them even the opportunity for natural ventilation. Interestingly, we found that respondents who had window/wall unit AC (the most common AC type) were more likely than respondents with central/split AC to also have opened windows as a heat-coping strategy. This finding is consistent with an earlier study done by Johnson and Long (2005) in Durham, NC.

We found that 14.7% of all respondents did not have AC in their sleeping environment. However, only 5.8% of all respondents were without any AC at home in 2015 summer. This figure is less than the 11% found by DOHMH's 2011 telephone survey (Lane et al. 2013) and by the 2014 NYC Housing and Vacancy Survey (NYCHVS) (NYC DHPD 2016). The discrepancy may be due to the fact that our sample on the whole is whiter, more affluent, and more educated than the NYC adult population. This may also explain why we did not find a significant difference in thermal satisfaction due to gender, race, or education level whereas several previous studies have found associations between heat-related mortality risks, and race and education attainment (Madrigano et al. 2015; Michelozzi et al. 2005; O'Neill et al. 2003; Rosenthal et al. 2014; Schwartz 2005).

Despite our sample being more affluent, the cost of running AC was still a major concern for most, so much so that almost half of all respondents said it was at least a fairly great financial burden. This means that the actual average financial barrier to AC access at home in NYC is likely greater than reflected in our survey. This finding is consistent with the survey by DOHMH and by Sheridan (2007) in four cities in North America. More importantly, we suggest that "financial burden of AC use" may be a better disparity measure than income alone, as it has a stronger association with bedroom thermal satisfaction.

Individual factors such as self-reported physical health and quality of life showed the largest effect sizes, which is not surprising as comfort is intricately linked to health and wellbeing. Being knowledgeable about how best to ventilate one's home was also associated with higher thermal satisfaction with a medium sized effect. Although we could not verify respondent's actual ventilation knowledge or how it benefited their heat-coping strategy, it is well known in thermal comfort research that *perceived* control (regardless of actual control) of one's thermal environment leads to greater satisfaction (Nikolopoulou and Steemers 2003). This may also in part explain why homeowners (particularly house owners) were found to be more thermally satisfied – they did not have to defer to landlords or other residents in the same building to modify their homes. Indeed, the notion of perceived control may be the ultimate advantage of having a higher socioeconomic status, which has been consistently linked to better health, comfort, quality of life and wellbeing.

Unsurprisingly, the use of AC and use frequency were significantly associated with greater bedroom thermal satisfaction. Running the AC longer per night was shown to have a small effect in increasing satisfaction, though this small advantage may not justify the behavior of the "overtime" AC users who kept the AC on even when not in the bedroom. More importantly, setting AC to a lower temperature provided no additional benefit. In fact, 14% of the AC users complained that AC was often too cold. The median AC set temperature for summer 2015 was 70°F (21.1°C) (average ± SD: 20.6°C ±2.9 or 69°F±5.2). As a comparison, a Hong Kong study (Lin and Deng 2006) found 56% of its surveyed sample to prefer temperature below 22°C (71.6°F) but a quarter of their respondents also complained of being too cold. Of note is that the 70°F average AC set temperature is lower than the average minimum outdoor temperature at night during the hottest months (July: 22.4°C/72.3°F and August: 22.0°C/71.6°F), but not during the beginning and end of the summer (June: 18.0°C/64.4°F and September: 19.1°C/66.4°F). These findings suggest that occupants may benefit from more mindful use of AC, such as starting with higher set temperature and lowering it only when discomfort is felt; or utilizing energy saver or timer functions to modulate the length and amount of cooling automatically. In fact, in their *Ready New York: Beat the Heat* guidance brochure the NYC Office of Emergency Management (OEM) recommended setting the AC *no lower* than 78°F (NYC OEM 2014). These measures of efficient AC use, however, may be difficult to implement because we found that only 66% of the AC users can set their AC to a specific temperature, and 28.7% of the AC users did not have an energy saver function available on their AC unit.

Studies have shown that the range of thermal comfort is narrower and more rigid for people accustomed to air-conditioned environments (Zhang et al. 2013). It has also been suggested that the ubiquity of AC in commercial and many work places, as well as the increasing affordability of AC units have raised people's expectations and aspirations for comfort (Cândido et al. 2010; de Dear and White 2008). The health implication of an artificially lowered level of thermal acceptability is not yet clear. But because exposure to heat is necessary for the body to develop protective physiological changes, some researchers have speculated that habituation to an air-conditioned environment may reduce physiological acclimatization and make people more susceptible to extreme heat (Kovats 2013). Being accustomed to air-conditioned environments may also decouple behavioral adaptations such as drinking more fluid and wearing less clothes that may otherwise have been undertaken subconsciously as it gets hotter outside but now must be explicitly prompted such as via heat advisories issued by the department of health and weather services. To some extent this decoupling may be evident in our study: respondents were more reliant on heat-coping strategies that modify the environment than the individual person. For example, while almost three quarters of respondents indicated they had ever used AC as a heat-coping strategy while sleeping during summer 2015, less than one third noted they wore less clothes to sleep and less than a quarter reported drinking more fluid or using lighter bedding (Figure 2).

We observed a small effect of AC type on satisfaction: respondents who had central/split system AC were more satisfied with their bedroom thermal condition than respondents who had window/wall unit AC. This is interesting because heat-related health impact studies have found only central AC to be a protective factor whereas room AC (i.e. window/wall unit AC) had little effect on heat-related mortality (O'Neill et al. 2005; Rogot et al. 1992). There are a number of reasons why window/wall unit AC may not be as effective as central/split AC in achieving thermal satisfaction (or health). First, window and wall units are generally less energy efficient than central systems (DOE 2016). They also only distribute the cooled air from a single point, which can prevent effective mixing depending on the location of the unit and the geometry as well as the furniture in the room. Second, the installation of the window/wall unit creates a physical aperture on the building façade that often lead to large crevices around the AC unit, not to mention the unit itself has vents which allow air to freely pass through. This can cause unwanted infiltration during both summer and winter. Central/split systems do not have this problem because the condenser and the air-handling units are separate by design.

Electric fan use was associated with a *lower* level of satisfaction (compared to non-fan users who mostly relied on AC). In fact, more frequent fan use was associated with lower bedroom thermal satisfaction, though the effect size was small. Health research remains uncertain regarding electric fan's effectiveness. Most studies have not found it to be a protective factor (Bouchama et al. 2007; Kilbourne et al. 1982; Naughton et al. 2002; Semenza et al. 1996). There are even some suggestions that it may have adverse effects when used improperly (EPA 2006; Gupta et al. 2012). As Semenza et al. (1996) pointed out, health studies on the use of electric fans is complicated because it would involve the consideration of other factors such as whether the fan is used in conjunction with an open or closed window and where it is positioned. Nevertheless, most studies conceded that any possible positive benefits from the fan would be minimal compared to AC (Hajat et al. 2010; Semenza et al. 1996).

Among fan users, respondents who had ceiling fans were significantly more satisfied than respondents who used other types of fans. This is not unexpected because ceiling fans, due to their location and size, are better able to circulate air throughout a room rather than just creating local drafts. The fact that the most common fan type is ceiling fan suggests that existing guidelines regarding fan use may need to provide more nuanced details with considerations of the types, size, and positions of fans. Indeed, Jay et al. (2014) found most heat protection guidelines to have exaggerated the risk of fan use during extreme heat. Quite the contrary, their modeling analysis suggested that fan use could increase the critical air temperature at which cardiovascular and thermal strain occur by 3–4 °C.

Finally, we found that respondents who were 65 or older were significantly more satisfied with their bedroom thermal environment than younger respondents. Our result is not the first instance where older adults were found to have greater thermal satisfaction. A field survey conducted by Indraganti and Rao (2010) in Hyderabad also suggested that older subjects to be more tolerant of the thermal environment than their younger counterparts.

Although the financial burden of AC use had a medium effect on bedroom thermal satisfaction, it is possible other factors not investigated in our study also contributed to the higher level of thermal satisfaction for respondents who were 65+ and who were retired. One possible explanation is that people of advanced age may perceive temperature differences less acutely than do younger individuals (Kilbourne 1997). Furthermore, older persons also tend to have more cognitive deficits such as dementias or Alzheimer's disease that can impair their perception of environmental conditions and threshold of suffering (Conti et al. 2007; Kilbourne 1997). Perception is of particular importance as it has been found that people, even the elderly, often do not feel that they are vulnerable to heat-related health impacts (Abrahamson et al. 2009; Åström et al. 2011; Lane et al. 2013; Sheridan 2007). In these cases, adaptive responses would need to be externally prompted via advisories or public service announcements; and even explicitly instructed such as by one's doctors, care providers, or neighbors.

4.1. Limitations

A key limitation of this study is that the data came from self-reported responses, which were subject to recall bias especially because the respondents were asked about their experiences and behaviors over the course of an entire summer season. Respondents may also have different interpretations of the Likert scale, such that one person's "very satisfied" may only equate to another's "somewhat satisfied". Similarly, one respondent's "occasionally" could be the same as another's "rarely".

Respondents who employed multiple heat-coping strategies during the 2015 summer may have used one or a combination of strategies on any given night. While it is likely that strategies modifying the person were used alongside strategies modifying the sleeping thermal environment, our questionnaire could only capture general behaviors and patterns. Specific interactions of personal and environmental modifications will be explored in future research. But to the best of our knowledge, this is the first study that examined the combination of heat strategies and the motivations behind those choices in a survey with a 500+ sample size.

5. Conclusions

Humans spend approximately one third of life sleeping. The environmental conditions of the home, in particular the bedroom, consequently have an important impact on comfort, overall health, and well-being. Yet at present we have little knowledge of the environmental conditions inside homes or their variability. Even less well documented and understood is the role occupants play in controlling the indoor thermal environment via the use of cooling appliances or window operations. We conducted the questionnaire study presented in this work specifically to fill that gap in knowledge. While the data confirmed much that is already known, such as the high penetration of AC usage and the association between AC use and thermal satisfaction, collected responses from this study also revealed patterns of use that had not been elucidated before. Furthermore, to the best of our knowledge, this survey study is the first in the US to also collect usage patterns and associated thermal satisfaction for electric fan use and window operations. A notable finding is that more frequent electric fan use at night during summer was associated with less satisfaction in the thermal conditions of the sleeping environment. In contrast, respondent bedroom thermal satisfaction increased with AC use frequency. Although we found that AC use was significantly associated with greater bedroom thermal satisfaction, keeping the AC on longer per night or at a lower set temperature provided little to no additional benefits. In spite of this, nearly a quarter of AC users reported running the AC almost all day and all night throughout the entire summer. The average set temperature of 70°F was also markedly below the 78°F recommended by NYC OEM. These findings suggest that, while AC use may be inevitable and necessary to combat heat in the summer in NYC especially under a warming climate, there is room for improvement in using AC more efficiently, especially in tandem with more frequent use of personal adjustments such as wearing less clothes and using lighter bedding. Finally, the results from this survey study expand our currently limited knowledge of indoor heat exposure and associated health impacts, and can aid the design of future detailed monitoring campaigns.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Abrahamson V, Wolf J, Lorenzoni I, Fenn B, Kovats S, Wilkinson P, et al. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. J Public Health (Oxf). 2009; 31(1):119–126. DOI: 10.1093/pubmed/fdn102 [PubMed: 19052099]

Alvarez GG, Ayas NT. The impact of daily sleep duration on health: a review of the literature. Progress in cardiovascular nursing. 2004; 19(2):56–59. [PubMed: 15133379]

Åström DO, Forsberg B, Rocklöv J. Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. Maturitas. 2011; 69(2011):99–105. DOI: 10.1016/j.maturitas.2011.03.008 [PubMed: 21477954]

Bach V, Telliez F, Libert JP. The interaction between sleep and thermoregulation in adults and neonates. Sleep Medicine Reviews. 2002; 6(6):481–492. DOI: 10.1053/smrv.2001.0177 [PubMed: 12505480]

Bodenhofer B, Krone M, Klawonn F. Testing noisy numerical data for monotonic association. Inform Sci. 2012; 245:21–37.

Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. Archives of Internal Medicine. 2007; 167(20):2170–2176. [PubMed: 17698676]

Cândido C, de Dear R, Lamberts R, Bittencourt L. Cooling exposure in hot humid climates: are occupants 'addicted'. Architectural Science Review. 2010; 53(1):59–64. DOI: 10.3763/asre.2009.0100

Carskadon, MA.; Dement, WC.; Hajat, S.; Armstrong, B.; Wilkinson, P. Normal Human Sleep: An Overview. In: Kryger, MH.; Roth, T.; Dement, WC., editors. Principles and Practice of Sleep Medicine. 5. Philadelphia, PA: Saunders/Elsevier; 2011. p. 16-26.

Center for Disease Control and Prevention (CDC) CFDCAP. Heat illness and deaths-new york city, 2000–2011. MMWR Morbidity and mortality weekly report. 2013; 62(31):617. [PubMed: 23925170]

Conti S, Masocco M, Meli P, Minelli G, Palummeri E, Solimini R, … Vichi M. General and specific mortality among the elderly during the 2003 heat wave in Genoa (Italy). Environ Res. 2007; 103(2):267–274. DOI: 10.1016/j.envres.2006.06.003 [PubMed: 16890219]

de Dear, R.; White, S. Residential air conditioning, thermal comfort and peak electricity demand management. Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge; Cumberland Lodge, Windsor, UK. April 27–29 2008; 2008.

EPA. Excessive heat events guidebook. US Environmental Protection Agency, Office of Atmospheric Programs; 2006.

Gupta S, Carmichael C, Simpson C, Clarke MJ, Allen C, Gao Y, … Murray V. Electric fans for reducing adverse health impacts in heatwaves. Cochrane Database of Systematic Reviews. 2012; (7)

Hajat S, O'Connor M, Kosatsky T. Health effects of hot weather: from awareness of risk factors to effective health protection. The Lancet. 2010; 375(9717):856–863. DOI: 10.1016/S0140-

Heller, HC.; Edgar, DM.; Grahn, DA.; Glotzbach, SF. Sleep, thermoregulation, and circadian rhythms. In: FMJ, editor. Handbook of Physiology, sect 4: environmental physiology. New York: Oxford University Press; 1996. p. 1361-1374.

Horne J. Human slow wave sleep: a review and appraisal of recent findings, with implications for sleep functions, and psychiatric illness. Experientia. 1992; 48(10):941–954. [PubMed: 1426145]

Indraganti M, Rao KD. Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations. Energy and Buildings. 2010; 42(3):273–281. DOI: 10.1016/j.enbuild.2009.09.003

Jay O, Cramer MN, Ravanelli NM, Hodder SG. Should electric fans be used during a heat wave. Appl Ergon. 2015; 46(Pt A):137–143. DOI: 10.1016/j.apergo.2014.07.013 [PubMed: 25134988]

Johnson T, Long T. Determining the frequency of open windows in residences: a pilot study in Durham, North Carolina during varying temperature conditions. J Expo Anal Environ Epidemiol. 2005; 15(4):329–349. DOI: 10.1038/sj.jea.7500409 [PubMed: 15536488]

Kayaba M, Ihara T, Kusaka H, Iizuka S, Miyamoto K, Honda Y. Association between sleep and residential environments in the summertime in Japan. Sleep Med. 2014; 15(5):556–564. DOI: 10.1016/j.sleep.2013.11.784 [PubMed: 24709308]

Kilbourne EM, Choi K, Jones TS, Thacker SB. Risk factors for heatstroke: A Case-Control Study. JAMA: The Journal of the American Medical Association. 1982; 247(24):3332. [PubMed: 7087076]

Kilbourne, EM. Heat waves and hot environments. In: Noji, EJ., editor. The public health consequences of disasters. Oxford: Oxford University Press; 1997. p. 245-269.

Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, … Engelmann WH. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of exposure analysis and environmental epidemiology. 2001; 11(3):231–252. [PubMed: 11477521]

Krauchi K, Cajochen C, Werth E, Wirz-Justice A. Functional link between distal vasodilation and sleep-onset latency? Am J Physiol Regul Integr Comp Physiol. 2000; 278(3):R741–8. [PubMed: 10712296]

Lan L, Pan L, Lian Z, Huang H, Lin Y. Experimental study on thermal comfort of sleeping people at different air temperatures. Building and Environment. 2014; 73:24–31.

Lane K, Wheeler K, Charles-Guzman K, Ahmed M, Blum M, Gregory K, … Matte T. Extreme heat awareness and protective behaviors in New York City. J Urban Health. 2014; 91(3):403–414. DOI: 10.1007/s11524-013-9850-7 [PubMed: 24297476]

Lin Z, Deng S. A questionnaire survey on sleeping thermal environment and bedroom air conditioning in high-rise residences in Hong Kong. Energy and Buildings. 2006; 38(11):1302–1307. DOI: 10.1016/j.enbuild.2006.04.004

McGeehin MA, Mirabelli M. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environmental Health Perspectives. 2001; 109(Suppl 2):185. [PubMed: 11359685]

Mendell MJ, Smith AH. Consistent pattern of elevated symptoms in air-conditioned office buildings: a reanalysis of epidemiologic studies. American journal of public health. 1990; 80(10):1193–1199. [PubMed: 2400029]

National Centers for Environmental Information (NCEI). [accessed 15.03.2016] Quality Controlled Local Climatological Data (QCLCD). 2016. https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/quality-controlled-local-climatological-data-qclcd

National Weather Service (NWS). [accessed 12.04.2016] National Weather Service New York, NY Excessive Heat Page. 2016. http://www.weather.gov/okx/excessiveheat

National Weather Service (NWS). [accessed 12.04.2016] The Heat Index Equation. http://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml

Naughton MP, Henderson A, Mirabelli MC, Kaiser R, Wilhelm JL, Kieszak SM, et al. Heat-related mortality during a 1999 heat wave in Chicago. American journal of preventive medicine. 2002; 22(4):221–227. [PubMed: 11988377]

Nikolopoulou M, Steemers K. Thermal comfort and psychological adaptation as a guide for designing urban spaces. Energy and Buildings. 2003; 35(1):95–101.

NYC Administrative Code Title 27 Chapter 1 Subchapter 12 Article 6 Standard of Natural Ventilation §746.

NYC Administrative Code Title 27 Chapter 2 Subchapter 3 Article 1 Lighting and Ventilation §2058.

NYC Department of Housing Preservation and Development (DHPD). [accessed 25.01.2016] New York City Housing and Vacancy Survey (NYCHVS). 2014. http://www.census.gov/housing/nychvs/

NYC Office of Emergency Management (OEM). [accessed 03.12.2015] Ready New York: Beat the Heat. https://www1.nyc.gov/assets/em/downloads/pdf/heat_brochure_english.pdf

O'Neill MS, Zanobetti A, Schwartz J. Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. J Urban Health. 2005; 82(2):191–197. DOI: 10.1093/jurban/jti043 [PubMed: 15888640]

Ostro B, Rauch S, Green R, Malig B, Basu R. The effects of temperature and use of air conditioning on hospitalizations. Am J Epidemiol. 2010; 172(9):1053–1061. DOI: 10.1093/aje/kwq231 [PubMed: 20829270]

Philip P, Chaufton C, Orriols L, Lagarde E, Amoros E, Laumon B, … Sagaspe P. Complaints of Poor Sleep and Risk of Traffic Accidents: A Population-Based Case-Control Study. PLoS One. 2014; 9(12):e114102.doi: 10.1371/journal.pone.0114102 [PubMed: 25494198]

R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria: 2015. https://www.R-project.org/

Rogot E, Sorlie PD, Backlund E. Air-conditioning and mortality in hot weather. American Journal of Epidemiology. 1992; 136(1):106–116. [PubMed: 1415127]

Rosekind MR, Gregory KB, Mallis MM, Brandt SL, Seal B, Lerner D. The cost of poor sleep: workplace productivity loss and associated costs. J Occup Environ Med. 2010; 52(1):91–98. DOI: 10.1097/JOM.0b013e3181c78c30 [PubMed: 20042880]

Schmidt-Kessen W, Kendel K. The influence of room temperature on night-sleep in man. Research in Experimental Medicine. 1973; 160(3):220–233. [PubMed: 4350670]

Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, Wilhelm JL. Heat-related deaths during the July 1995 heat wave in Chicago. The New England Journal of Medicine. 1996; 335(2):84–90. [PubMed: 8649494]

Seppanen O, Fisk WJ. Association of ventilation system type with SBS symptoms in office workers. Indoor Air. 2002; 12(2):98–112. [PubMed: 12216473]

Sheridan SC. A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. Int J Biometeorol. 2007; 52(1):3–15. DOI: 10.1007/s00484-006-0052-9 [PubMed: 17024398]

Strand LB, Carnethon M, Biggs ML, Djoussé L, Kaplan RC, Siscovick DS, et al. Sleep Disturbances and Glucose Metabolism in Older Adults: The Cardiovascular Health Study. Diabetes Care. 2015; 38(11):2050–2058. DOI: 10.2337/dc15-0137 [PubMed: 26384390]

US Department of Energy (DOE). [assessed 27.06.2016] Spring and Summer Energy-Saving Tips. http://energy.gov/energysaver/spring-and-summer-energy-saving-tips

US Department of Energy (DOE). [accessed 15.01.2016] Room Air Conditioners. http://energy.gov/energysaver/room-air-conditioners

US Energy Information Administration (EIA). [accessed 12.04.2016] Air conditioning in nearly 100 million U.S. homes. 2011 Aug 19. http://www.eia.gov/consumption/residential/reports/2009/air-conditioning.cfm

Van Someren EJ, Raymann RJ, Scherder EJ, Daanen HA, Swaab DF. Circadian and age-related modulation of thermoreception and temperature regulation: mechanisms and functional implications. Ageing Res Rev. 2002; 1(4):721–778. [PubMed: 12208240]

Zhang Y, Chen H, Meng Q. Thermal comfort in buildings with split air-conditioners in hot-humid area of China. Building and Environment. 2013; 64:213–224. DOI: 10.1016/j.buildenv.2012.09.009

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Highlights

- AC was the most commonly used bedtime heat-coping strategy during the 2015 summer.
- More frequent AC use was associated with higher bedroom thermal satisfaction.
- Setting the AC temperature lower did not increase bedroom thermal satisfaction.
- More frequent electric fan use was associated with lower bedroom thermal satisfaction.
- Cost, noise, and fresh air dominated resident concerns when choosing a cooling strategy.

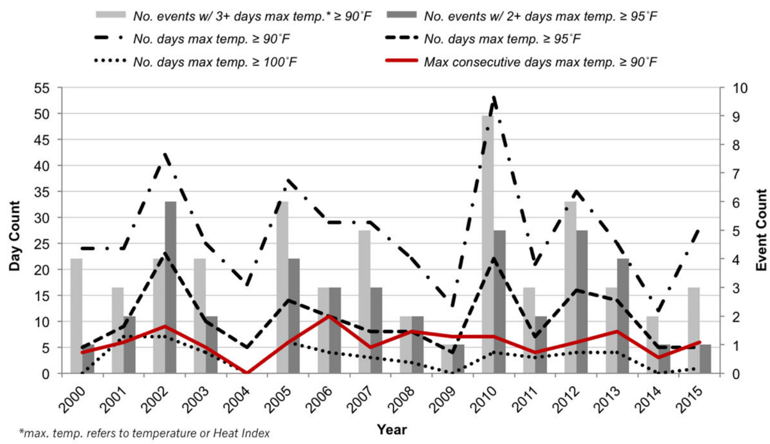

Figure 1.

Number of days per year with a maximum temperature or heat index of at least 90/95/100°F measured at the La Guardia Airport weather station (data source National Weather Service)

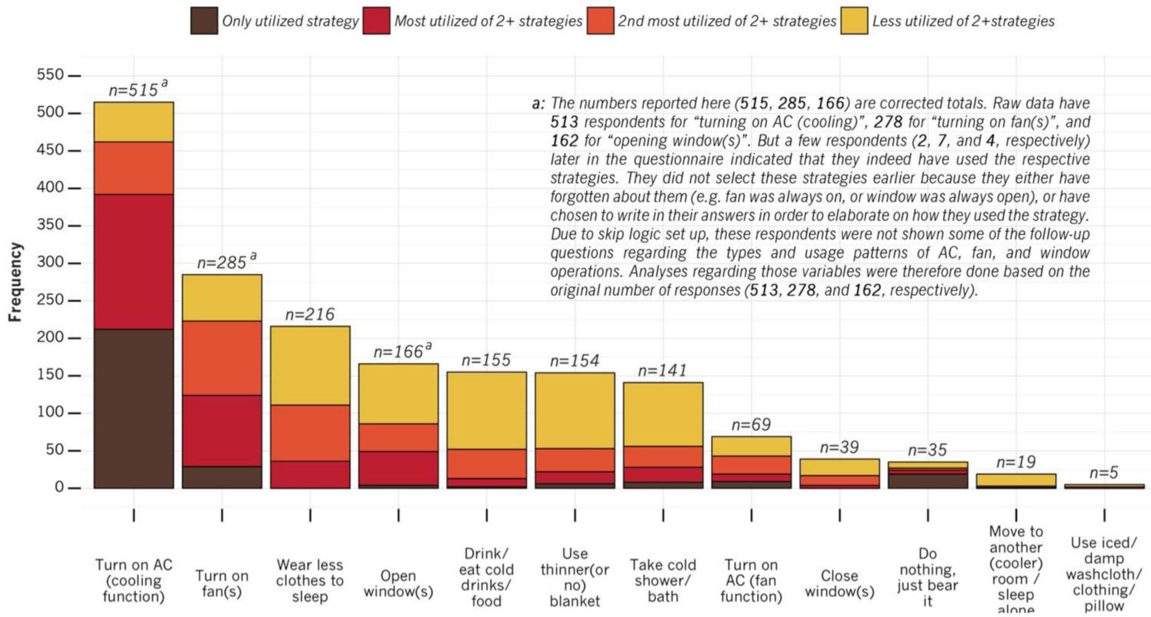

Figure 2.

Respondents' bedtime heat-coping strategies for summer 2015

Figure 3.

Influencing factors behind chosen and unused heat-coping strategies

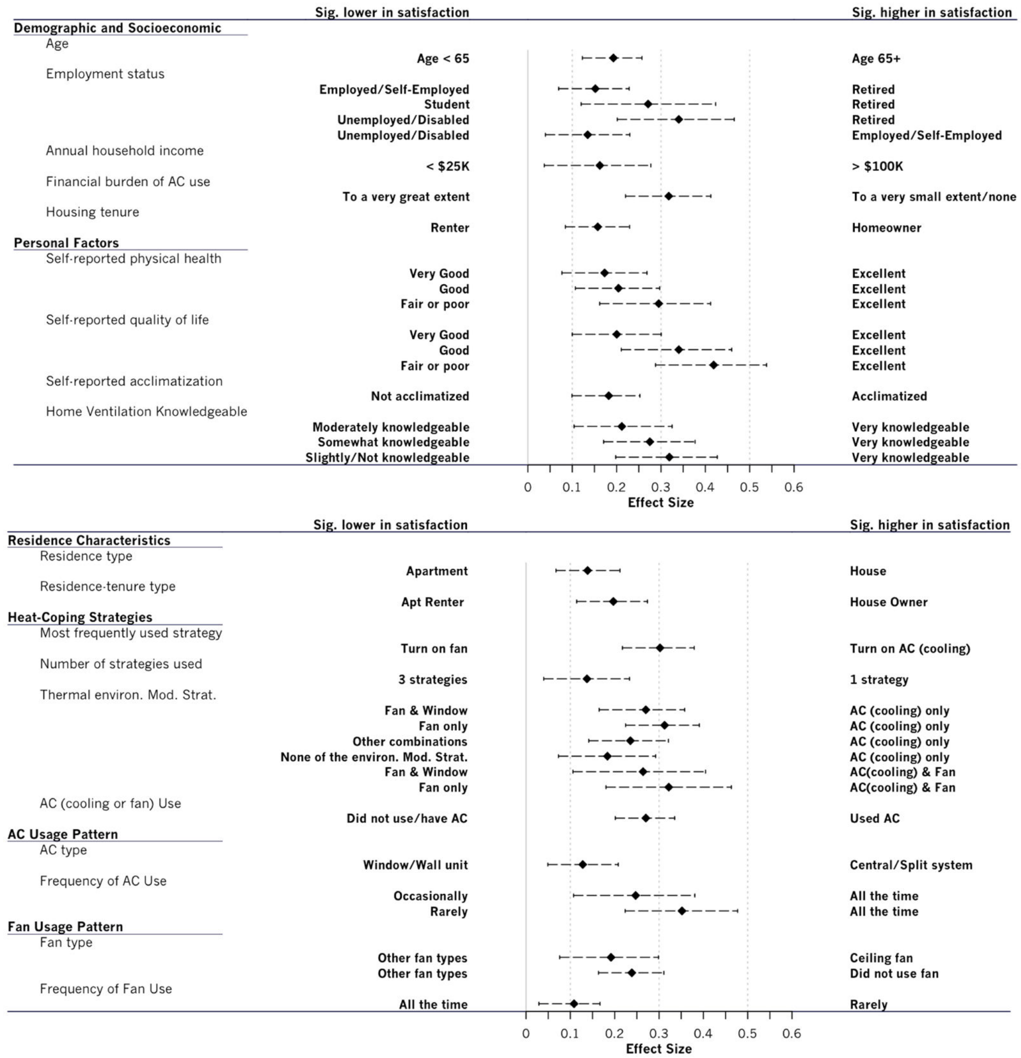

Figure 4.

Effect sizes of Mann-Whitney U test pairwise comparisons with bootstrapped 95% confidence intervals for statistically significant variables

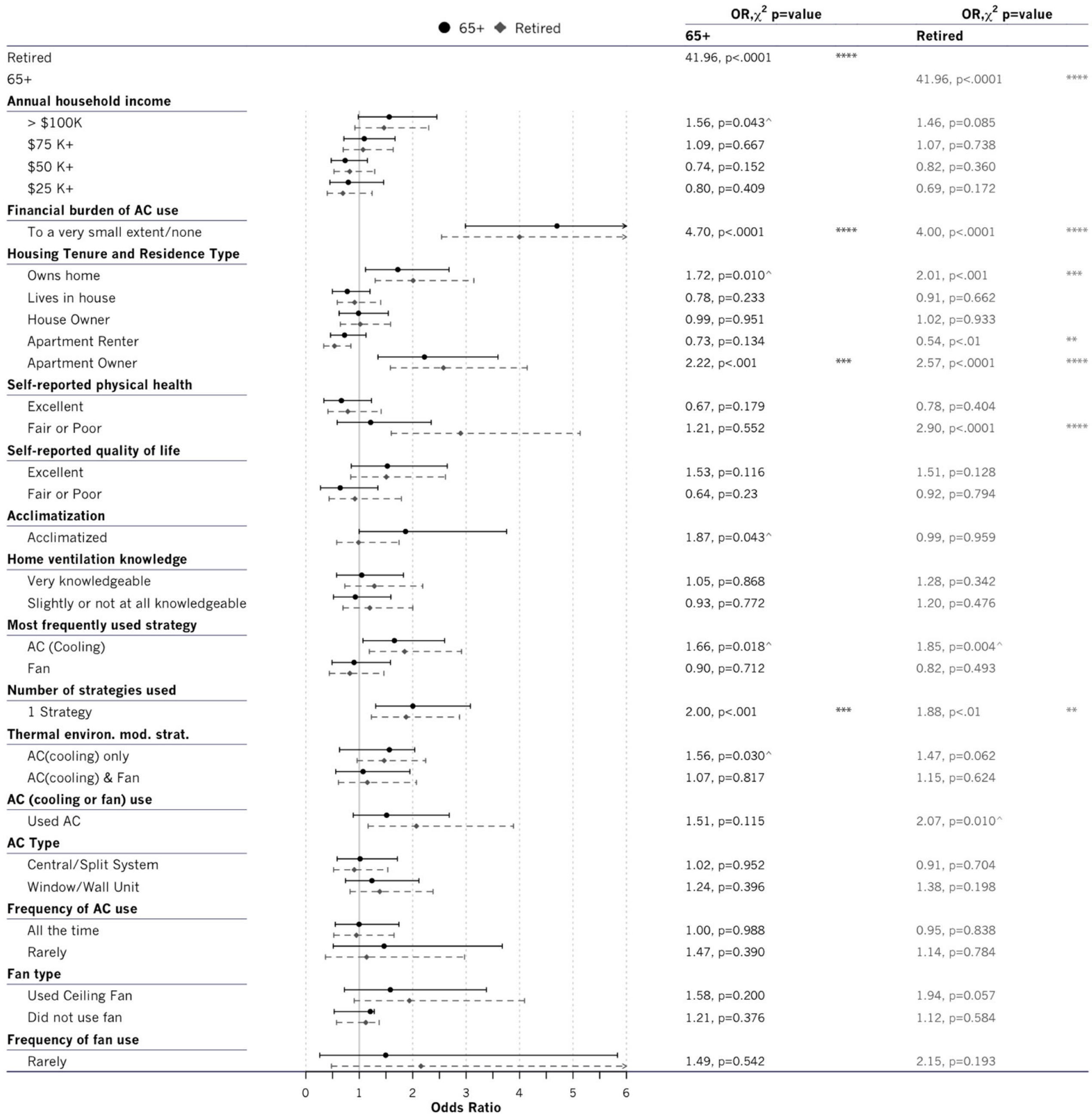

Figure 5.

Comparisons of respondents 65+ and respondents who were retired against respondents <65, and respondents *not* retired (OR=1); * ***p***<.05, ** ***p***<.01, *** ***p***<.001, **** ***p***<.0001; ^ means the Pearson's Chi-Square statistic was significant but standard residuals in individual cells were not (i.e. barely significant therefore interpret with caution)

Table 1

Breakdown of AC and electric fan usage patterns, and window operation

	N	(%)
AC Type		
Window/Wall Unit	427	(70.9%)
Central/Split System	146	(24.3%)
Portable and Other Types	29	(4.8%)
subset total	602[a]	(100.0%)
AC Control		
can be set to specific temperature	401	(66.6%)
can only be set on an abstract scale (e.g. 1–10)	43	(7.1%)
can only be set to low, medium, or high	132	(21.9%)
can only be turned on or off	21	(3.5%)
other situation	5	(0.8%)
subset total	602[a]	(100.0%)
Use AC Energy Saver Function		
Always	133	(25.9%)
Frequently	69	(13.5%)
Occasionally	84	(16.4%)
Rarely	32	(6.2%)
Never	48	(9.4%)
Function not available	147	(28.7%)
subset total	513[b]	(100.0%)
Concurrent electric fan use		
Always	34	(21.0%)
Very often	38	(23.5%)
sometimes	35	(21.6%)
Rarely	24	(14.8%)
Never	31	(19.1%)
subset total	162[c]	(100.0%)
Concurrent window opening		
Always	3	(3.3%)
Very often	3	(3.3%)
sometimes	8	(8.8%)
Rarely	13	(14.3%)
Never	64	(70.3%)
subset total	91[d]	(100.0%)
AC installed in home?		
Yes	658	(93.2%)

	N	(%)
No	48	(6.8%)
total	706	(100.0%)
AC installed in bedroom?		
Yes	602	(85.3%)
No	104	(14.7%)
total	706	(100.0%)
Had AC in BR, but had AC elsewhere in home?		
Yes	453	(81.6%)
No	102	(18.4%)
subset total	555[e]	(100.0%)
No AC in BR, but had AC elsewhere in home?		
Yes	56	(56.6%)
No	43	(43.4%)
subset total	99[f]	(100.0%)
Total number of AC in home (incl. not installed)		
None	41	(5.8%)
Central AC (excl. split)	119	(16.9%)
One	172	(24.4%)
Two	208	(29.5%)
Three	107	(15.2%)
Four or more	59	(8.4%)
total	706	(100.0%)
Electric Fan Type		
Ceiling Fan	85	(30.6%)
Small Portable/Table Fan	80	(28.8%)
Standing/Pedestal Fan	69	(24.8%)
Column/Tower Fan	43	(15.5%)
Box Fan	41	(14.7%)
Window Fan	23	(8.3%)
Heavy-Duty Floor Fan	22	(7.9%)
subset total	278[g]	*not applicable; multiple choices allowed*
Position of Electric Fans		
Next to bed and/or blowing towards body to feel airflow	140	(72.5%)
In front of an open window	35	(18.1%)
Far away from bed and/or blowing away from body so NOT to feel airflow	21	(10.9%)
Anywhere in the bedroom where there is space	16	(8.3%)
Other locations	4	(2.1%)

	N	(%)
subset total	193[h]	*not applicable; multiple choices allowed*
Number of Electric Fans in Bedroom		
One	213	(76.6%)
Two	50	(18.0%)
Three of more	15	(5.4%)
subset total	278[g]	(100.0%)
Window Opening Patterns		
(Almost) always open	86	(53.1%)
Open a few hr. prior to bedtime and kept open throughout the night	20	(12.3%)
Open a few hr. prior to bedtime and closed in the middle of the night	4	(2.5%)
Open a few hr. prior to bedtime and closed when going to sleep	17	(10.5%)
Open just before getting in bed and kept open throughout the night	26	(16.0%)
Open just before getting in bed and closed in the middle of the night	7	(4.3%)
Other situation/varies	2	(1.2%)
subset total	162[i]	(100.0%)
Home Ventilation Knowledge		
Very knowledgeable	116	(16.4%)
Moderately knowledgeable	227	(32.2%)
Somewhat knowledgeable	230	(32.6%)
slightly or not at all knowledgeable	133	(18.8%)
total	706	(100.0%)
Extent cost is a barrier to using AC		
To a very great extent	193	(27.3%)
To a fairly great extent	116	(16.4%)
To a moderately great extent	145	(20.5%)
To a small extent	104	(14.7%)
To a very small extent or Not al all	148	(21.0%)
total	706	(100.0%)
AC Bill Responsibility		
Renter: AC bill included in rent	73	(10.3%)
Renter: Pay AC bill separately	271	(38.4%)
Owner: Responsible for all bills	362	(51.3%)
total	706	(100.0%)
Used de-humidifier?		
Yes	66	(9.3%)
No	640	(90.7%)
total	706	(100.0%)

Subset of respondents who…

[a]…used AC (cooling) OR AC (fan-only)

[b]…used AC (cooling)

[c]…used AC (cooling) AND electric fans

[d]…used AC (cooling) AND opened windows

[e]…have AC installed in bedroom (exclude those living in studio apartment)

[f]…did NOT have AC installed in bedroom (exclude those living in studio apartment)

[g]…used electric fans

[h]…used fans but have none-ceiling type fan(s)

[i]…opened windows

Table 2

Breakdown of AC and electric fan frequency and time period of use

	N	(%)	N	(%)	N	(%)
Frequency of Use						
	AC (cooling)		**AC (fan-only)**		**Electric Fan**	
All the time (every night)	120	(23.4%)	5	(7.2%)	52	(18.7%)
Very frequently (~90% of the nights)	121	(23.6%)	5	(7.2%)	76	(27.3%)
Frequently (~70% of the nights)	101	(19.7%)	5	(7.2%)	51	(18.3%)
A moderate amount (~50% of the nights)	78	(15.2%)	14	(20.3%)	47	(16.9%)
Occasionally (~30% of the nights)	63	(12.3%)	26	(37.7%)	36	(12.9%)
Rarely (~10% of the nights)	30	(5.8%)	14	(20.3%)	16	(5.8%)
subset total	513[b]	(100.0%)	69[j]	(100.0%)	278[g]	(100.0%)
Time Period of Use						
	AC (cooling)		**AC (fan-only)**		**Electric Fan**	
(Almost) always on	185	(36.1%)	18	(26.1%)	114	(41.0%)
Turned on few hr. (≥1 hr.) prior to getting in bed/when got home in the evening and turned off after waking up	85	(16.6%)	8	(11.6%)	21	(7.6%)
Turned on around the time (< 1 hr.) of getting in bed and turned off after waking up	119	(23.2%)	21	(30.4%)	100	(36.0%)
Turned on prior to bedtime but turned off in the middle of the night	81	(15.8%)	16	(23.2%)	19	(6.8%)
Turned on prior to bedtime but turned off when going to sleep	32	(6.2%)	4	(5.8%)	16	(5.8%)
Turned on sometime during the night and turned off after waking up	11	(2.1%)	2	(2.9%)	8	(2.9%)
subset total	513[b]	(100.0%)	69[j]	(100.0%)	278[g]	(100.0%)

Subset of respondents who…

[a] …used AC (cooling) OR AC (fan-only)

[b] …used AC (cooling)

[c] …used AC (cooling) AND electric fans

[d] …used AC (cooling) AND opened windows

[e] …have AC installed in bedroom (exclude those living in studio apartment)

[f]…did NOT have AC installed in bedroom (exclude those living in studio apartment)

[g]…used electric fans

[h]…used fans but have none-ceiling type fan(s)

[i]…opened windows