Original Contribution

The Effects of Temperature and Use of Air Conditioning on Hospitalizations

Bart Ostro*, Stephen Rauch, Rochelle Green, Brian Malig, and Rupa Basu

* Correspondence to Dr. Bart Ostro, Centre for Research in Environmental Epidemiology, Doctor Aiguader, 88, Barcelona 08003,
Spain (e-mail: bostro@creal.cat).

Several investigators have documented the effect of temperature on mortality, although fewer have studied its impact on morbidity. In addition, little is known about the effectiveness of mitigation strategies such as use of air conditioners (ACs). The authors investigated the association between temperature and hospital admissions in California from 1999 to 2005. They also determined whether AC ownership and usage, assessed at the zip-code level, mitigated this association. Because of the unique spatial pattern of income and climate in California, confounding of AC effects by other local factors is less likely. The authors included only persons who had a temperature monitor within 25 km of their residential zip code. Using a time-stratified case-crossover approach, the authors observed a significantly increased risk of hospitalization for multiple diseases, including cardiovascular disease, ischemic heart disease, ischemic stroke, respiratory disease, pneumonia, dehydration, heat stroke, diabetes, and acute renal failure, with a 10°F increase in same-day apparent temperature. They also found that ownership and usage of ACs significantly reduced the effects of temperature on these health outcomes, after controlling for potential confounding by family income and other socioeconomic factors. These results demonstrate important effects of temperature on public health and the potential for mitigation.

air conditioning; cardiovascular diseases; climate change; effect modifiers (epidemiology); hospitalization; respiratory tract diseases; temperature

Several investigators have documented the acute effect of temperature on mortality in the United States and Europe, as well as in developing nations (1–3). There have been far fewer studies, however, on the effects of temperature on morbidity outcomes, such as hospitalization (4–6). According to a recent report of the Intergovernmental Panel on Climate Change (7), global temperatures are expected to increase in the future, with more frequent and severe heat waves. Therefore, it is important to obtain a better understanding of these heat-associated health risks and susceptible populations for future surveillance and targeted interventions. In addition, relatively little is known about the effectiveness of proposed mitigation strategies, such as cooling shelters and personal use of air conditioners (ACs). Studies on the effects of actual AC use on temperature-related health outcomes are limited, since data are typically available for AC prevalence rather than AC use, and only for broad geographic regions. Thus, effects of AC may be confounded by other regional characteristics (8), such as demographic and economic factors. As a result, there is a need for more localized estimates of the effects of temperature on morbidity and on the effectiveness of AC use in mitigating these effects.

For several reasons, California serves as an ideal study area for examining the effects of AC use on temperature-related adverse health outcomes. First, it includes a large and diverse population residing within a wide array of climatic regions. Second, individual-level data at small levels of spatial scale over a majority of the state are available from surveys conducted by the California Energy Commission (9). Finally, income is less likely to confound estimates of AC effects in California. In general, incomes

are higher in the coastal regions but lower in the inland areas, such as the Central Valley. However, AC use is greater in the Central Valley, where the summers are much hotter, and many homes in the coastal areas lack AC (9).

In this study, we used temperature data collected during the warm season in California to estimate the impact of temperature on several disease-specific categories of hospitalization. To limit exposure misclassification, we limited our study to buffer areas with persons living in zip codes within 25 km of a temperature monitor. Next, we quantified the likely reduction in health impacts based on both ownership and use of ACs using individual-level data for each buffer. Finally, we examined the potentially confounding effect that local measures of family income might have on our effect estimates.

MATERIALS AND METHODS

Health outcome data

Data on disease-specific hospital admissions occurring from 1999 through 2005 were obtained from the Healthcare Quality and Analysis Division of the California Office of Statewide Health Planning and Development (10). We restricted our analysis to the warm season of May 1 through September 30, and we abstracted information on date of admission and primary diagnosis and patient's zip code of residence. On the basis of previous research (4, 5, 11), we considered several cardiovascular and respiratory diseases, as well as diabetes, dehydration, heat stroke, intestinal infectious diseases, and acute renal failure. Using ArcGIS, version 9.2 (12), we used the population-weighted centroid to assign each zip code to the closest temperature monitor in the same climate zone, up to a maximum distance of 25 km. Information on climate zones came from the California Energy Commission, which divides California into 16 zones based on weather, temperature, energy use, and other climatic factors. By requiring respondents assigned to a given monitor to be in the same climate zone, we attempted to reduce misclassification of temperature exposure. If more than 1 temperature monitor was within 25 km of the population centroid and was located in the same climate zone, residents of that zip code were assigned exposure from the closer monitor.

Weather data

Temperature data were obtained from 2 separate monitoring data sets: the California Irrigation Management Information System (13) and the US Environmental Protection Agency's Air Quality System (14). Mean, maximum, and minimum daily apparent temperature values in degrees Fahrenheit were calculated to account for temperature and relative humidity using a method that has been previously described (15).

AC and socioeconomic data

We obtained data on AC ownership and use from the 2004 California Residential Appliance Saturation Survey (RASS), a statewide utility survey sponsored by the California Energy Commission (9). From this survey, conducted in 2003, we used approximately 21,900 responses from 1,272 zip codes statewide in 53 out of 58 counties. This mailed survey employed a stratified random sample design for all metered customers served by the participating utility companies. The stratification variables for the individually metered customers were electric utility, age of the home, presence of electric heat, home type, and climate zone. Survey questions obtained information about whether respondents had AC in their residences, with separate questions for central AC and room AC units. Respondents were asked additional questions about their AC use during that year. Based on these responses, we calculated the separate prevalence of AC ownership and use for both central AC and room AC. Ultimately, responses were aggregated into 6 buffer-specific averages, including both prevalence and use of central AC only, room AC only, and either central AC or room AC. For the 10% of respondents who indicated the presence of AC but did not provide information on use, we assigned the buffer-specific rates of use obtained from the respondents with complete data.

To assess the relation between AC and socioeconomic status, we used the 2003 RASS survey question concerning annual household income to create a buffer-specific average estimate for income. We also used zip-code-level data from the 2000 US Census and created additional buffer-specific measures of median household income, population living in poverty, and population over 65 years of age. We determined buffer-specific estimates by weighting zip-code data by the associated population.

Similar to the spatial assignment of hospital data, each AC survey respondent was assigned to the closest temperature monitor within 25 km. Each buffer was required to have at least 25 respondents completing the RASS survey to be included in the analysis. Ultimately, there were 117 buffers with complete data.

Study design and data analysis

As in previous studies (11), we used a time-stratified case-crossover study design described by Levy et al. (16) and Janes et al. (17). In this method, temperature on the date of hospitalization (case) is compared with temperatures on several control days (referent periods) occurring on the same day of the week within the same month and year. Since all referent periods are selected within the same month as the hospitalization, seasonal or long-term effects are minimized. Besides examining the effect of same-day temperature (lag_0), we also considered the effects of temperature on previous days: from 1 day before hospitalization to 6 days before (lag_1–lag_6), as well as several cumulative averages of temperature, including same-day and previous day (lag_{0-1}), same day and the previous 3 days (lag_{0-3}), and same day and the previous 6 days (lag_{0-6}).

All analyses were conducted in 2 stages: First, we used the PHREG procedure in SAS statistical software (18) for conditional logistic regression and obtained beta estimates for each buffer area. Then we combined the buffer-specific beta estimates using a random-effects meta-analysis (19),

Table 1. Characteristics of California Climate Zones and Estimates of the Effect of Apparent Temperature (per 10°F (5.6°C) Change) on Hospitalization Obtained From Meta-Analysis of Buffer Areas, May–September 1999–2005

Climate Zone[a]	Reference City	Mean Apparent Temperature (°F)	AC Ownership[b], %	AC Use[b], %	Median Annual Income (From RASS), $	Effect on Respiratory Admissions		Effect on Cardiovascular Admissions	
						% Change per 10°F	95% CI	% Change per 10°F	95% CI
1	Arcata	NA	4.4	3.6	49,960	NA		NA	
2	Santa Rosa	61.7	43.2	40.1	66,787	6.8	2.8, 11.0	3.1	0.7, 5.5
3	Oakland	58.6	10.5	9.0	72,216	2.9	0.3, 5.6	2.0	0.2, 3.8
4	Sunnyvale	62.6	48.4	43.0	79,354	2.7	−0.7, 6.3	1.9	−0.3, 4.2
5	Santa Maria	60.7	14.7	10.4	65,005	7.8	−1.7, 18.1	9.8	3.6, 16.3
6	Los Angeles	64.5	31.4	24.4	72,013	7.0	2.1, 12.1	5.1	1.9, 8.4
7	San Diego	67.7	31.7	23.2	65,992	6.3	2.3, 10.5	4.9	2.2, 7.5
8	El Toro	69.5	55.0	47.9	55,133	5.6	3.2, 8.0	4.0	2.3, 5.8
9	Pasadena	69.5	74.6	67.9	58,698	2.9	1.6, 4.2	0.7	−0.2, 1.6
10	Riverside	70.9	86.6	78.4	60,905	0.3	−1.3, 1.9	−0.3	−1.4, 0.8
11	Red Bluff	72.2	88.6	85.8	54,400	0.7	−2.2, 3.7	1.6	−0.3, 3.6
12	Sacramento	68.9	86.0	81.9	68,384	0.7	−0.7, 2.1	0.2	−0.8, 1.1
13	Fresno	74.2	88.7	85.9	49,049	2.1	0.3, 4.0	−0.3	−1.5, 0.9
14	China Lake	77.8	87.7	85.1	50,796	0.8	−3.1, 4.8	−0.4	−3.0, 2.3
15	El Centro	86.8	97.5	95.2	64,177	−1.2	−4.3, 2.0	−0.4	−2.4, 1.7
16	Mount Shasta	61.7	56.0	52.3	65,195	−4.1	−14.4, 7.4	3.0	−4.4, 10.9

Abbreviations: AC, air conditioning; CI, confidence interval; NA, not available; RASS, Residential Appliance Saturation Survey.
[a] For map of climate zones, see Figure 1.
[b] Includes both central AC and room AC.

with the meta.summaries command in R statistical software's RMETA package (20). Meta-analyses were conducted for each of the climate zones and then for the entire state. Odds ratios and 95% confidence intervals were calculated for a 10°F (5.6°C) change in apparent temperature (daily mean, maximum, or minimum). The results are presented as the percent excess risk of hospital admission, defined as: (odds ratio − 1) × 100%.

To assess effect modification by AC, we performed a random-effects meta-regression in Stata, version 8, using the revised METAREG package (21). In univariate analysis, the buffer-specific beta estimates were regressed on each of the buffer-specific AC prevalence and use metrics. In a second model, we included adjustment for buffer-specific income, as measured by the RASS survey.

Sensitivity analyses

We conducted several sensitivity analyses specifically for hospitalizations for respiratory disease and cardiovascular disease using different analysis parameters. First, to examine possible exposure misclassification associated with distance to the monitor, we reduced the inclusion radius to 10 km instead of 25 km. Second, to assess the effect of only assigning cases to monitors in the same climate zone, we conducted another analysis that allowed people to be assigned to a monitor in a different climate zone, provided that their zip code was still within 25 km of the monitor. Third, to assess any possible bias created by excluding buffers lacking sufficient AC survey data, we reanalyzed

the first-stage monitor-level data using all 209 temperature monitors and associated buffers in the state. Fourth, to determine whether the effects of AC on the associations between hospitalization and cardiovascular and respiratory disease differed by age, we conducted separate analyses for persons under age 65 years and persons aged 65 years or older.

RESULTS

The final data set included 117 buffers whose zip codes encompassed approximately 25.9 million people, or about 87% of California's total population, as per the 2000 US Census. Table 1 gives descriptive statistics on temperature, income, and AC use and prevalence for the buffers in each climate zone, and Figure 1 shows the location of each climate zone. Table 1 also displays the climate-zone-specific effect estimates relating temperature to hospitalization for respiratory and cardiovascular diseases. The results indicated several associations with temperature and larger effect estimates for the coastal climate zones versus inland climate zones (climate zone 1 was omitted because of a lack of data).

In Table 2 and Figure 2, the results of the meta-analysis are summarized for temperature and hospitalizations using cases who met our monitoring proximity criteria and resided in buffers with sufficient AC usage data. The number of cases of each disease is also displayed in Table 2. In general, the best model fit, according to t statistics, was observed for
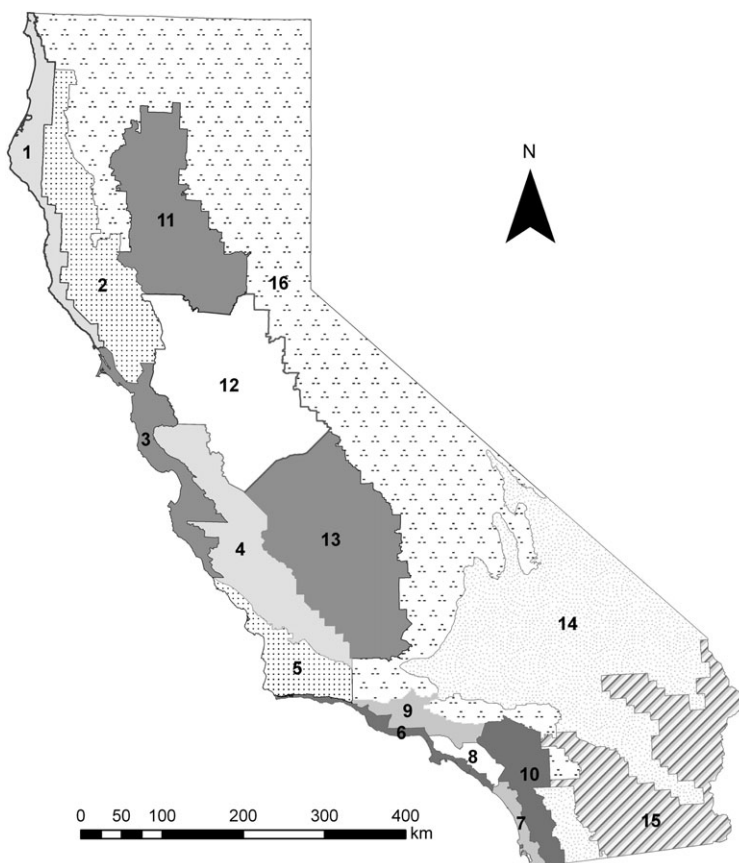
Figure 1. Map of California showing the state's 16 climate zones.

same-day (lag_0) mean or maximum apparent temperature. For example, the effect of temperature was immediate for respiratory and cardiovascular disease (Figure 3). Thus, all subsequent results shown are for lag_0. Significant associations were observed between temperature and many of the cause-specific hospital admissions, including hospitalization for total cardiovascular disease, ischemic heart disease, ischemic stroke, total respiratory disease, pneumonia, dehydration, heat stroke, diabetes, and acute renal failure.

Table 3 summarizes the overall prevalence and use of the buffer-specific AC metrics and their impact on the association between temperature and hospital admissions. Overall, 64.9% of the survey respondents owned an AC and 60.1% had used an AC during the year. Owning an AC, using an AC, owning central AC, and using central AC were highly correlated ($r > 0.97$). As a result, these measures had a very similar impact on the reduction of the temperature-hospitalization effect estimate. In addition, prevalence and use of "any" AC and of central AC were not significantly correlated with income ($r \approx -0.1$). In contrast, ownership and use of room AC was negatively correlated with income ($r = -0.42$ and $r = -0.43$), indicating that the greater the family income, the less likely was the presence of a room AC.

In our second stage of analysis, we regressed the first-stage monitor-specific beta coefficients obtained from the temperature-hospitalization analysis on the various measures of AC prevalence. Table 3 displays the results for different measures of AC prevalence and use on hospitalization for respiratory disease. For example, a 10% change in the proportion using central AC relates to a difference of 0.5% in the excess risk associated with a temperature increase of 10°F (i.e., the effect is reduced from 2.6% to 2.1% per 10°F). The impacts of owning or using any AC and using central AC were very similar, given their high correlation, while owning or using only a room AC was not associated with any reduction in the temperature effect on respiratory admissions. The AC effect estimate did not vary when any of the socioeconomic status covariates (income from the RASS survey, census-based median household income, percentage over age 65 years, and percentage living in poverty in the census tract) were included in the meta-regression. Since the results were very similar, only RASS income data are presented in Table 3.

Table 4 summarizes the effect modification of AC prevalence on other outcomes. Owning and using an AC and owning and using central AC modified the effects of temperature for several of the disease categories examined, including pneumonia, all cardiovascular disease, ischemic heart disease, ischemic stroke, dehydration, and heat stroke.

Table 2. Percent Increase in Excess Risk of Hospitalization per 10°F (5.6°C) Change in Mean, Maximum, and Minimum Same-Day Apparent Temperature Obtained From Meta-Analysis of Buffer Areas, California, May–September 1999–2005

	ICD-9 Code	Mean		Maximum		Minimum		No. of Cases
		%	95% CI	%	95% CI	%	95% CI	
Respiratory disease	450–519	2.6	1.4, 3.7	1.8	1.2, 2.4	0.6	−0.6, 1.8	473,104
Pneumonia	480–486	3.9	2.4, 5.4	2.7	2.1, 3.4	1.3	−0.3, 2.9	179,470
Asthma	493	0.9	−1.5, 3.3	1.2	−0.2, 2.6	−1.7	−4.5, 1.2	61,266
Chronic obstructive pulmonary disease	491–492	0.7	−0.9, 2.4	1.1	0.1, 2.1	−0.8	−2.8, 1.3	130,712
Cardiovascular disease	390–459	1.4	0.5, 2.4	1.0	0.4, 1.5	−0.8	−1.7, 0.2	1,014,444
Ischemic heart disease	410–414	1.7	0.4, 2.9	1.2	0.6, 1.9	−0.6	−1.8, 0.7	330,917
Stroke	430–438	1.6	−0.01, 3.3	1.2	0.4, 2.1	−1.5	−3.0, −0.01	184,267
Ischemic stroke	433–436	3.3	1.6, 5.0	2.2	1.4, 3.1	−0.6	−2.1, 0.92	145,752
Myocardial infarction	410	0.4	−1.5, 2.4	0.8	−0.3, 1.9	−3.0	−5.0, −1.0	118,816
Heart failure	428	−0.8	−2.4, 0.7	0.2	−0.7, 1.1	−2.6	−4.3, −0.8	161,012
Dehydration	276.5	11.2	9.0, 13.6	5.7	4.4, 6.9	6.2	3.9, 8.6	64,815
Heat stroke	992	364	283, 462	166	135, 201	153	103, 216	941
Diabetes	250	4.0	1.9, 6.2	1.8	0.9, 2.8	1.7	−0.8, 4.2	98,476
Acute renal failure	584	10.2	7.2, 13.2	4.9	3.4, 6.4	7.2	3.3, 11.1	34,878
Intestinal infection	001–009	2.6	−0.5, 5.7	1.2	−0.6, 3.0	1.3	−2.4, 5.2	22,258

Abbreviations: CI, confidence interval; ICD-9, *International Classification of Diseases*, Ninth Revision.

Again, these measures were robust to additional adjustment by socioeconomic status. Table 4 also displays the relative change in the first-stage beta coefficients relating to a 10% increase in AC prevalence. For example, for hospitalization for ischemic heart disease, a 10% increase in prevalence is associated with a 0.6% difference in the temperature-associated effect, corresponding to a 36% reduction in the first-stage coefficient.
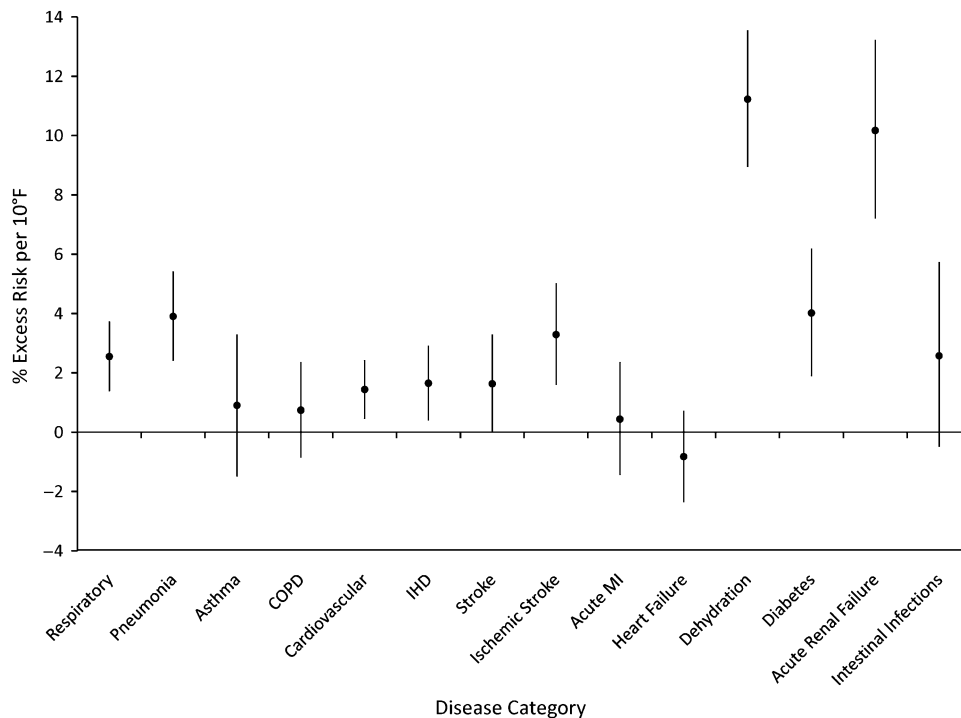

Figure 2. Disease-specific percent excess risk of hospitalization per 10°F (5.6°C) increase in same-day mean apparent temperature, California, May–September 1999–2005. Heat stroke (excess risk = 364%, 95% confidence interval: 283, 462) was omitted because of incompatibility of the scale of the result. COPD, chronic obstructive pulmonary disease; IHD, ischemic heart disease; MI, myocardial infarction. Bars, 95% confidence interval.
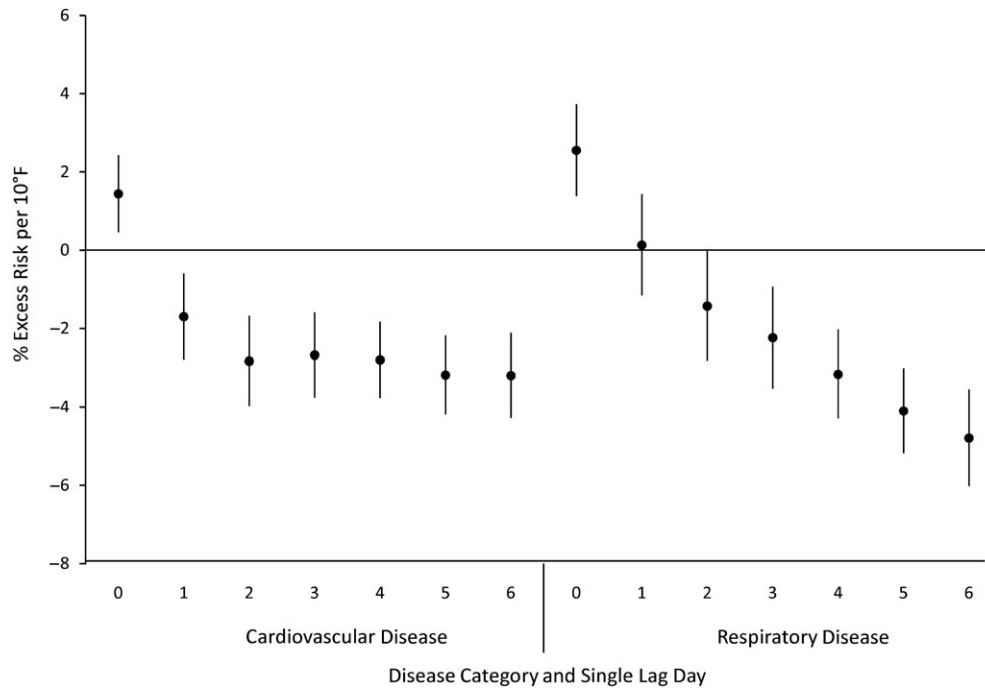
Figure 3. Percent excess risk of cardiovascular and respiratory disease hospitalization per 10°F (5.6°C) increase in mean apparent temperature, by single lag day from lag$_0$ to lag$_6$, California, May–September 1999–2005. Bars, 95% confidence interval.

Our sensitivity analyses focused on cardiovascular and respiratory effects. The analysis using a 10-km buffer generated results similar to those obtained using the 25-km buffer. However, when the monitor-level analysis was conducted without respect to climate zone by allowing individuals to be assigned to monitors in a different climate zone within 25 km, the effect of temperature on both outcomes was reduced, and for respiratory admissions, the AC effect modification was no longer statistically significant. Thus, there is some evidence that taking into account climatology and geography increased the precision of our es-

timates and the study power. We observed results similar to our original first-stage results when all 209 buffers in the state (including those buffers excluded from the original analysis because of lack of AC data) were examined. Finally, the effect of AC differed by age for both outcomes. For cardiovascular disease, a 10% increase in AC ownership resulted in an absolute reduction in excess risk of 0.76% (95% confidence interval (CI): 0.29, 1.22) for persons aged 65 years or older versus a reduction of 0.46% (95% CI: −0.01, 0.92) among persons under age 65 years. For respiratory disease, the absolute reduction in excess risk was

Table 3. Reduction in Respiratory Hospitalization per 10°F (5.6°C) Change in Apparent Temperature, According to Various Measures of Air Conditioner Use, California, May–September 1999–2005

AC Metric	Prevalence[a], %	Unadjusted Effect Estimate[b]	95% CI	Income-Adjusted Effect Estimate[a]	95% CI
Ownership of central or room AC	64.9	0.51	0.02, 1.0	0.50	0.01, 1.0
Use of central or room AC	60.1	0.52	0.03, 1.0	0.51	0.02, 1.0
Ownership of central AC	54.6	0.53	0.03, 1.0	0.54	0.04, 1.0
Use of central AC	50.1	0.54	0.04, 1.0	0.55	0.05, 1.1
Ownership of only a room AC	10.3	0.06	−2.0, 1.9	0.45	−2.7, 1.7
Use of only a room AC	10.0	−0.10	−1.9, 2.1	0.26	−2.6, 2.0

Abbreviations: AC, air conditioner/ing; CI, confidence interval.

[a] Based on responses to the Residential Appliance Saturation Survey (9).

[b] Absolute reduction in the percent excess risk of respiratory hospital admission per 10°F from a 10% increase in each AC metric. For example, a 10% increase in owning central AC reduces the estimated respiratory effect of a 10°F change in temperature by 0.53.

Table 4.   Effect of a 10% Increase in Air Conditioning Ownership on the Temperature-Mortality Relation, California, May–September 1999–2005

| Outcome | Reduction in Excess Risk[a] | | | |
| | Absolute Reduction | | Relative Reduction | |
	%	95% CI	%	95% CI
Respiratory disease	0.51	0.02, 1.0	19.9	0.7, 39.1
Pneumonia	0.76	0.2, 1.3	19.4	5.3, 33.5
Chronic obstructive pulmonary disease	0.1	−0.6, 0.7	4.2	−56.6, 63.6
Cardiovascular disease	0.71	0.3, 1.1	49.1	19.9, 78.3
Ischemic heart disease	0.60	0.1, 1.1	36.2	4.6, 67.6
Stroke	0.63	−0.02, 1.3	38.4	−1.5, 78.1
Ischemic stroke	0.67	0.02, 1.3	20.4	0.6, 40.1
Diabetes	0.04	−0.8, 0.9	1.0	−20.1, 22.0
Acute renal failure	0.21	−0.9, 1.3	2.1	−8.4, 12.4
Dehydration	1.29	0.6, 2.0	11.5	4.9, 18.1
Heat stroke	14.74	7.0, 21.8	4.0	1.9, 6.0

Abbreviations: AC, air conditioning; CI, confidence interval.

[a] "Absolute" signifies the effect of a 10% increase in AC ownership on reducing the estimated percent change in mortality per 10°F (5.6°C), while "relative" signifies the percent reduction in the temperature-mortality coefficient due to the AC increase.

0.52% (95% CI: 0.05, 1.00) for persons aged 65 years or older versus a reduction of 0.33% (95% CI: −0.20, 0.85) for persons under age 65 years.

DISCUSSION

Using data based on 117 buffer areas, we observed significant associations between increased apparent temperature and risk of hospitalization for several outcomes. The effects were observed using both daily average temperature and maximum apparent temperature. Using buffer-specific data, we also observed significant reductions in temperature-related hospitalizations when central AC was present or used. Although we performed the meta-regressions to determine the effect of AC on the temperature-hospitalization relation, the meta-regressions may have served to correct the biased estimates of exposure occurring when AC use was not taken into account in the first-stage regression. Therefore, the adjustment of effects by AC use may have more to do with correcting exposure measurement error than effect modification. In addition, we found no evidence that income or other measures of socioeconomic status confounded the relation between temperature and hospitalization in California. Finally, our analysis indicated that hospital admissions were most strongly associated with unlagged temperature, a finding consistent with other temperature studies (22). For some outcomes, such as cardiovascular disease and respiratory disease, there was a suggestion of harvesting of the temperature effects because the effect estimates for lags 1–6 were null or negative. However, for other

outcomes, such as dehydration, the effects remained significantly positive out to lag 3.

To our knowledge, this is one of the first studies that used localized measures of temperature exposure, AC prevalence and use, and family income. Rather than using Metropolitan Statistical Area- or large county-based estimates of AC prevalence, we were able to assign AC prevalence using smaller spatial clusters. The use of more local data was likely to reduce measurement error, which was also reduced by keeping monitor assignments within similar climate zones. We found that in California, prevalence or use of central AC was not associated with income. This is probably a result of the positive gradient for temperature and AC prevalence from coastal to inland areas but a mild negative gradient for family income. Specifically, based on our sample of 117 buffer areas in California, the correlation between central AC prevalence and family income was −0.04. In contrast, the correlation of these 2 variables based on a national study using American Housing Survey data for 53 metropolitan areas was −0.32 (2). The inverse association in this national study probably represents broad regional differences in income, demographic characteristics, and AC prevalence and would not account for income differences within these large metropolitan areas. In our study, income did not confound the observed negative association between central AC use and hospital admissions. Our finding that the prevalence of central AC, but not room AC, modified the heat-mortality association has also been reported in other studies that had access to both of these AC measures (23, 24). It is not clear whether room AC was ineffective in mitigating health effects or whether too few people in our study had room AC to observe effects.

Several investigations of ambient temperature and mortality have examined modification by AC prevalence (23–28). However, none of these previous investigations of mitigation of temperature impacts focused on morbidity outcomes, such as hospitalizations. Anderson and Bell (2) analyzed 107 US metropolitan areas and reported associations between higher daily temperatures and all-cause and cardiovascular mortality. As in other studies, greater heat effects on mortality were observed in urban areas in the northeastern region of the United States. Analyses of these data for effect modification indicated that greater heat impacts per degree Fahrenheit were observed in metropolitan areas with higher income, unemployment, use of public transit, and population density and with lower AC prevalence—all characteristics associated with the Northeast. As Vedal (8) indicated, a variable measured ecologically such as AC may be associated with several other regional factors, making it difficult to attribute effect modification to any single factor. Thus, the observed effect modification may have been due to any or all of these factors, as well as unmeasured correlates. In addition, there is a greater likelihood of acclimatization in the warmer southern states, where, over time, people may adapt and become physiologically more tolerant to high ambient temperatures.

Curriero et al. (26) found an association between hotter temperatures and mortality in a sample of 11 large US metropolitan areas. Analysis for effect modification of this association using 2000 US Census data indicated that stronger

effects were observed in the North, in metropolitan areas with higher percentages of the population not finishing high school or living in poverty, and with a lower percentage of AC present in homes, based on AHS data. In addition, the authors indicated that acclimatization to higher temperatures may play a role in consistently warmer regions. Clearly, separating out the effect of regional AC use versus socioeconomic status factors in this 11-city study is challenging given the differences in other potential effect modifiers that vary by region. In addition, the AHS recorded data on AC prevalence but not AC use. While we observed very high correlations between AC prevalence and use in California, their relation for the nation as a whole is less certain. Similar issues of confounding by regional characteristics may persist in other studies (25, 27).

While we cannot entirely rule out the possibility that our AC measures may also have been correlated with other factors that modify the heat-hospitalization effect estimates, we attempted to minimize this likelihood. First, our data showed no correlation across the buffer areas between family income and either central AC prevalence or use. It is likely that the correlation with other measures of socioeconomic status was also low. Second, previous studies that have examined the impact of AC prevalence on the effects of either ambient temperature or outdoor air pollution have relied on census data on a large-scale level, such as county-wide averages. We were able to examine effects within relatively small areas around each temperature monitor. Third, we utilized AC prevalence and use data collected at the local level to minimize measurement error related to both temperature and use of AC. Fourth, previous studies in California have indicated that the association between heat and adverse health is not confounded by common air pollutants, such as ozone and fine particles (4, 15). Nevertheless, we cannot rule out the possibility of some confounding of our AC metrics. In addition, the survey data for AC prevalence and use were for only 1 year and may have changed during the study years.

In summary, we observed significant associations between heat and several disease-specific types of hospital admissions in California. We also observed that the use of central AC appeared to significantly reduce the risk from higher temperatures. We caution, however, that increased prevalence of residential AC might not be an effective long-term strategy in regions where temperatures continue to increase. Power brownouts and blackouts have often occurred during periods of high heat stress. In addition, until substitutes for carbon-based fuels are widely instituted, energy demands associated with increases in residential AC use will exacerbate the adverse effects associated with fuel combustion. This includes the health and welfare effects of both air pollution and changes in the global climate.

ACKNOWLEDGMENTS

REFERENCES

1. Basu R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environ Health*. 2009;8(1):40. (doi: 10.1186/1476-069X-8-40).
2. Anderson BG, Bell ML. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology*. 2009;20(2):205–213.
3. Hajat S, Armstrong BG, Gouveia N, et al. Mortality displacement of heat-related deaths: a comparison of Delhi, São Paulo, and London. *Epidemiology*. 2005;16(15):613–620.
4. Green RS, Basu R, Malig B, et al. The effect of temperature on hospital admissions in nine California counties. *Int J Public Health*. 2010;55(2):113–121.
5. Knowlton K. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environ Health Perspect*. 2009;117(1):61–67.
6. Schwartz J, Samet JM, Patz JA. Hospital admissions for heart disease: the effects of temperature and humidity. *Epidemiology*. 2004;15(6):755–761.
7. Intergovernmental Panel on Climate Change, United Nations. *Climate Change 2007: Synthesis Report*. (IPCC Fourth Assessment Report). Geneva, Switzerland: Intergovernmental Panel on Climate Change; 2007. (http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf). (Accessed November 8, 2009).
8. Vedal S. Does air conditioning modify the health effects of exposure to outdoor air pollution? *Epidemiology*. 2009;20(5):687–688.
9. California Energy Commission. *California Statewide Residential Appliance Saturation Study: Final Report*. (Report no. 400-04-009). Sacramento, CA: California Energy Commission; 2004. (http://www.energy.ca.gov/appliances/rass/). (Accessed June 19, 2009).
10. California Office of Statewide Health Planning and Development. *California Office of Statewide Health Planning and Development (OSHPD) Patient Discharge Data* [database]. Sacramento, CA: California Office of Statewide Health Planning and Development; 1999–2005. (http://www.oshpd.ca.gov/HID/Products/PatDischargeData/PublicDataSet/index.html). (Accessed January 5, 2009).
11. Basu R, Ostro BD. A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *Am J Epidemiol*. 2008;168(6):632–637.

12. Beyer HL. *Hawth's Analysis Tools for ArcGIS*. Redlands, CA: Environmental Systems Research Institute; 1995–2008.

13. California Irrigation Management Information System, Office of Water Use Efficiency, California Department of Water Resources. *CIMIS Data* [database]. Sacramento, CA: California Department of Water Resources; 2009. (http://wwwcimis.water.ca.gov/cimis/data.jsp). (Accessed March 20, 2009).

14. US Environmental Protection Agency. *Technology Transfer Network (TTN) Air Quality System (AQS) Data Mart* [database]. Washington, DC: US Environmental Protection Agency; 2009. (http://www.epa.gov/ttn/airs/aqsdatamart/access/interface.htm). (Accessed April 21, 2009).

15. Basu R, Feng WY, Ostro BD. Characterizing temperature and mortality in nine California counties. *Epidemiology*. 2008; 19(1):138–145.

16. Levy D, Lumley T, Sheppard L, et al. Referent selection in case-crossover analyses of acute health effects of air pollution. *Epidemiology*. 2001;12(2):186–192.

17. Janes H, Sheppard L, Lumley T. Case-crossover analyses of air pollution exposure data: referent selection strategies and their implications for bias. *Epidemiology*. 2005;16(6):717–726.

18. SAS Institute Inc. *SAS Statistical Software*. Cary, NC: SAS Institute Inc; 2008.

19. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7(3):177–188.

20. R Development Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2008.

21. Stata Corporation. *STATA, Version 8*. College Station, TX: Stata Corporation; 2003.

22. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev*. 2002;24(2):190–202.

23. 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.

24. Rogot E, Sorlie PD, Backlund E. Air-conditioning and mortality in hot weather. *Am J Epidemiol*. 1992;136(1):106–116.

25. Medina-Ramón M, Schwartz J. Temperature, temperature extremes, and mortality: a study of acclimatisation and effect modification in 50 US cities. *Occup Environ Med*. 2007;64: 827–833.

26. Curriero FC, Heiner KS, Samet JM, et al. Temperature and mortality in 11 cities of the eastern United States. *Am J Epidemiol*. 2002;155(1):80–87.

27. Braga AL, Zanobetti A, Schwartz J. The time course of weather-related deaths. *Epidemiology*. 2001;12(6):662–667.

28. Braga AL, Zanobetti A, Schwartz J. The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities. *Environ Health Perspect*. 2002;110(9):859–863.