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Cooler rooms on a hotter planet? Household coping strategies, climate change, and air conditioning usage in rural China

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ABSTRACT

Ownership and usage of air conditioners (AC) have increased dramatically in the past few decades as global warming and the increasing occurrence of extreme hot weather have become major concerns. However, there is a lack of household-level studies on the effect of climate change on AC energy consumption and usage patterns, especially for developing countries, which have great potential for AC adoption and usage. This study employed data from the Chinese Residential Energy Consumption Survey, matched with weather data, to analyze the effect of climate change on AC usage at the household level by using AC energy consumption and usage time as AC usage indicators. The result shows that cooling degree days significantly influence both AC energy consumption and AC usage time, while the average relative humidity affects only AC usage time. In addition, we find that other socio-economic variables, including dwelling age, occupation, and dwelling size, also influence AC usage.

1. Introduction

As our planet continues to get hotter, climate change is causing growing concern worldwide. The annual average temperature has increased by approximately 1 °C over the past 100 years in many countries, regardless of geographical location or initial temperature. However, conditions may worsen further, and the global temperature will continue to increase. According to predictions by the International Energy Agency (IEA), the cooling degree days (CDDs)[1] will, on average, increase by 25.4% worldwide from 2016 to 2050, implying a rapid increase in demand for cooling, the most direct coping strategy in a warming world. Fig. 1 illustrates the dramatic rise in final energy consumption for indoor cooling in selected countries or regions over the past few decades. For example, China's cooling-related energy consumption has soared from 7 TWh in 1990 to 450 TWh in 2016. In particular, energy consumption for cooling in China has risen most rapidly in the last decade, from around 45 TWh in 2000 to more than 450 TWh in 2016.

As the use of air conditioners (ACs) is widely regarded to be an important adaptation or coping strategy to a warming world, the ownership and usage of ACs is expected to have a close relation with temperature. From a macro-level perspective, the relationship between AC ownership and temperature is clear, although it may be influenced by economic factors. Fig. 2 shows the AC ownership per capita of the year 2016 in different Chinese provinces. It can be seen that AC ownership at the provincial level is closely related to both income and temperature. For provinces with a similar level of net disposable income per capita (represented by the diameter of the circles), AC ownership increases with an increase in the average annual temperature. However, it is also notable that provinces with the highest AC ownership, such as Beijing, Tianjin, Shanghai, Jiangsu, and Zhejiang, all have a high level of income per capita, indicating the importance of income for AC ownership.

A better understanding of the relationship between climate change and AC ownership and usage is of great importance as it allows for a more precise forecast of China's future energy growth. According to the International Energy Agency, air conditioning use will emerge as one of the top drivers of demand for global electricity over the next three decades. In reality, China's electricity consumption has more than quadrupled in the past two decades, rising from 12,485 tons of oil equivalent (toe) in 2000 to 72,404 toe in 2016. As the earth gets warmer, the demand for cooling will very likely lead to an increase in China's future electricity demand. Compared with those in the urban area, the households in rural area could be more vulnerable to climate change due to their lower incomes, which may affect their AC usage as an coping strategy to hotter climate. This paper provides evidence on

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[1] A cooling degree day (CDD) is a measurement that quantifies the demand for energy needed to cool buildings. It is the number of degrees that a day's average temperature is above the reference temperature.

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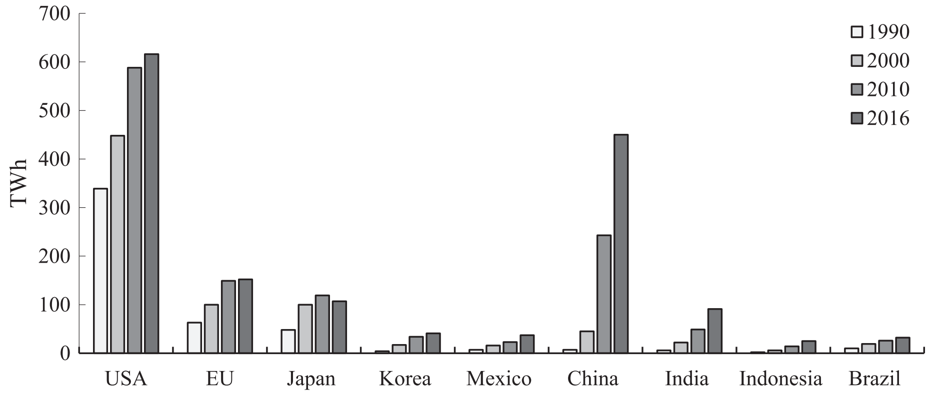

Fig. 1. Final energy consumption for indoor cooling in selected countries Data source: IEA (2018).

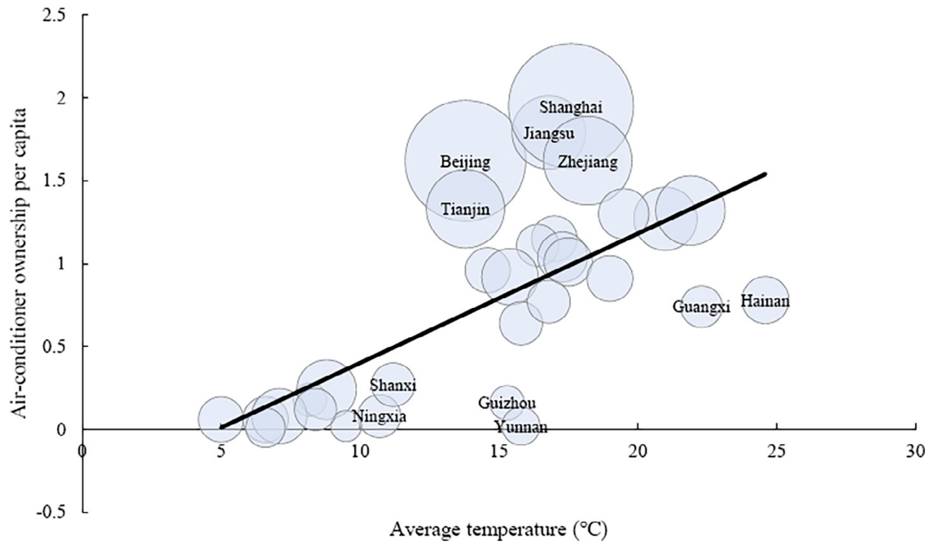

Fig. 2. AC ownership and temperature by Chinese provinces in 2016. Notes: The diameter of each circle represents the net disposable income per capita in each province. Data source: China Statistical Yearbook 2016.

the effect of climate change on AC usage and cooling energy consumption in rural China by matching data from the Chinese Residential Energy Consumption Survey with weather data from the National Meteorological Information Center. We find that the cooling degree days influence both the energy consumption and usage time of ACs significantly, while the average relative humidity affects only the AC usage time. Further, we find that other socio-economic variables, including dwelling age, occupation and age of household head, also influence AC usage.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the data used for the study and presents the econometric models used. Section 4 illustrates the estimated results of the household-level effect of climate change on the usage and energy consumption of ACs. Finally, Section 5 concludes the study.

2. Literature review

Climate change has an impact on agriculture, forestry, biodiversity, water resources, coastal and marine resources, public health, and energy [1]. There are different adaptation strategies to climate change problems, such as adopting new crop varieties, changing planting time, homestead gardening, and using air-conditioners [2,3]. Among these adaptation behaviors, adopting air-conditioners is an effective way to reduce the health risks caused by climate change [3]. Due to the importance and prevalence of AC use, many studies focus on the relationship between climate change and AC usage. For instance, focusing on the relationship between climate change and electricity demand in summer in California by controlling for the influence of population growth, AC market saturation, and other factors and Miller et al. show that extreme high temperatures increase electricity consumption in summer [4]. Also, there is empirical evidence showing that the residential energy consumption in the US rises sharply in years with extreme high temperatures [5]. Although there are a lot of related studies based on time-series variation or aggregated panel data, the existing literature raises concerns of omitted variable bias and that using household-level panel data on energy consumption may help identify how consumers around the world respond to weather shocks [6].

There have been some household-level studies focusing on the relationship between climate change and AC usage or adoption behavior in developed countries. Auffhammer [7] uses household-level electricity billing history in California; the results show that hot weather does increase residential electricity consumption, but the amount is modest. Cian et al. [8] use household-level survey data to analyze the relationship between warming climate and AC adoption, and the results suggest that exposure to a warmer climate raises the probability that a household will adopt air conditioning in OECD countries [8]. There are also studies focusing on predicting the increase of energy consumption caused by climate change with the household-level data. For example, Auffhammer and Aroonruengsawat [9] use household-level data and a downscaled version of the National Center for Atmospheric Research global circulation models to predict the increase of electricity. Their results indicate that total consumption for the households considered may increase by up to 55% by the end of the century.

As for the related household-level studies in developing countries, studies on the relationship between climate change and AC usage or adoption behavior are rare. Most studies in developing countries are descriptive, focusing on AC usage patterns. However, there is some evidence from India and Mexico on the relationship between climate change and AC usage. In India, the second largest developing country, the sensitivity of electricity demand to climate change is closely related to household income; that is, higher incomes are associated with higher electricity demand when high temperatures occur [10]. As for Mexico, there is a sharp increase in electricity consumption on high temperature days, while there is no obvious decline on low temperature days [11]. In terms of descriptive studies on AC usage patterns in developing countries, a lot of work has been done, especially in China. For instance, Wang et al. [12] find that 54% of households in Guangdong own more than two ACs. Besides, urban residents in Shanghai begin to use ACs if the temperature reaches 25–27 ℃, while residents in Tianjin begin to use ACs when the temperature reaches 27.6 ℃ and stop using them when the temperature decreases to below 23.3 ℃ [13,14]. The specific study focusing on the use of ACs in the student dormitories of Chinese universities shows that over 50% of the students start to use ACs when the temperature reaches 30 ℃ [15]. In addition to the research on temperature thresholds that trigger AC usage, some recent studies find that most Chinese residents use ACs in the period from June to September (e.g.,[14]), with a daily duration of between 3 and 10 h (e.g., [13]). Moreover, previous studies, both in China and other countries, find that AC usage habits are generally affected by the characteristics of household members, such as age and education level. For example, having household members with a higher education level is associated with less dependency on ACs, while higher income leads to increased AC use (e.g., [12,13]). Further, a Hong Kong study suggests that low-income households tend to have more frugal AC usage habits to reduce energy expenditure (e.g.,[16]).

There is a lack of household-level studies on the effect of climate change on AC energy consumption and usage patterns, especially for developing countries, which have great potential for AC usage and are experiencing strong energy poverty [17]. This paper addresses this gap. We employed data from the Chinese Residential Energy Consumption Survey (CRECS), matched with weather data from the National Meteorological Information Center, to investigate the effect of climate change on the AC usage patterns of households in China. The result shows that the cooling degree days influence both AC energy consumption and usage time significantly, while the average relative humidity affects only AC usage time. Further, we find that other socio-economic variables, including dwelling age, occupation, and age of household head, also affect AC usage patterns.

3. Data and method

3.1. Data sources

In order to analyze the effect of climate change on household AC usage patterns, this study used AC energy consumption and AC usage time as indicators of AC usage. As for the key independent variables, we focus on the CDD and average daily relative humidity in the summer months. Several household control variables are also used.

Household AC usage data were obtained from the Chinese Residents Energy Consumption Survey 2014 (CRECS 2014), which surveyed the energy consumption behavior of Chinese rural residents in detail throughout 2013. The dataset contains detailed data on household characteristics, household consumption of each type of energy, and energy consumption of related electric appliances. There are two specific reasons why we use the CRECS 2014 dataset: First, CRECS 2014 focused on the energy consumption behavior of rural residents, who are more vulnerable to climate change. Compared to CRECS in other years, CRECS 2014 allows us to explore the adaptation behavior of this vulnerable group. Secondly, CRECS 2014 includes the geographical location of households, providing latitude and longitude levels. Considering that microclimates vary considerably across the county, the CRECS 2014 dataset enables us to accurately calculate the weather conditions faced by each household. We do this by matching household data with meteorological data. The latter are gathered from the National Meteorological Information Center (NMIC) of China, and the original data contain the latitude and longitude, daily mean temperature, humidity, air pressure, precipitation, wind speed, and so on, for around 820 meteorological stations nationwide.

To match the weather information with household data, we used the inverse distance weighting (IDW) method to calculate the weather variables at the household level. That is, we took the weighted average of weather variables across the stations within 200 km of each household, where the weight for station i is:

$$w_i = \frac{(\frac{1}{d_i})^p}{\sum_{j=1}^{N_h} (\frac{1}{d_i})^p} i, j = 1, 2, 3, \cdots, N_h \tag{1}$$

where d_i represents the distance between station i and household h; N_h is the number of meteorological stations within 200 km of household h; and p is the index that affects the weight of each meteorological station, which is set to one. Thus, we matched the household data with weather data for the year 2013.

Since only yearly household data were available, we also needed to convert the daily weather variables into annual variables. For the temperature variables, this study used CDD to transform the daily average temperature, T, into annual data, as follows [18]:

$$CDD = \sum_{T \geq T_0} (T - T_0) \tag{2}$$

CDD represents the sum of the number of degrees by which the daily average temperature exceeds reference temperature T_0 during a year. It is suggested that 18.3℃ is a verified optimal reference temperature for research on the relationship between climate change and AC market saturation [19]. Therefore, in this study, we set the reference temperature as $T_0 = 18.3$ °C. As for the humidity variable, we used the average daily relative humidity in the summer months (June, July, and August).

3.2. Descriptive analysis

This study focused on temperature and humidity, which were found to be the most relevant amongst the various weather variables in determining AC usage. In Table 1, the average CDD in 2013 across households is 1600.04 ℃, with a minimum and maximum CDD of 295.96 ℃ and 2618.98 ℃, respectively. The average relative humidity in the summer of 2013 across households is 69.30%.

Variables such as household and dwelling features were included in the analysis below as control variables. The descriptive statistics are summarized in Table 1, indicating that the average household size is 4.53 people, and that there is a large variation in household income. Further, it shows that 30% of household heads work in the private sector, while only a few heads work in public departments. Considering the education of household heads, 78% have below a high school level, 13% received a high school education, and only 9% have college education or above. For the variable of dwelling size, we divided it into 10 intervals from less than $15m^2$ to over $250m^2$, and the size of most household dwellings is over $90m^2$. For the variable of dwelling building year, we divided it into 8 intervals from before 1949 to after 2009; most dwellings were built after 1980.

In this study, we used AC cooling energy consumption, average daily usage time, and annual AC usage time as indicators of AC usage. As for AC energy consumption, which is a continuous variable, the

Table 1
Descriptive statistics of variables.

Type	Variable	Definition	Mean	Std. Dev.	Min	Max
Meteorological variable	*CDD_2013*	CDD in 2013(°C)	1600.04	413.38	295.96	2618.98
	savgRHU	Average daily relative humidity in summer (%)	69.30	6.38	50.78	79.96
Household variables	*income*	Household income in 2013 (Yuan)	44642.81	34277.60	0	300,000
	household size	Number of household members	4.53	1.64	1	15
	gender	1 for male, 0 for female	0.85	0.36	0	1
	age	Age of household head	51.54	12.72	18	100
	work_public	1 for employed in public sector, 0 otherwise.	0.04	0.20	0	1
	work_private	1 for employed in private sector, 0 otherwise.	0.30	0.46	0	1
	work_other	1 for employed in other sectors, 0 otherwise.	0.66	0.47	0	1
	ethnic Han	1 for ethnic Han, 0 otherwise.	0.93	0.25	0	1
	edu_college	1 for educated at the college level or above, 0 otherwise.	0.09	0.28	0	1
	edu_high	1 for educated at or above the high school level but below college level, 0 otherwise.	0.13	0.34	0	1
	edu_low	1 for educated below high school level, 0 otherwise.	0.78	0.41	0	1
	living month	Number of months the household head lived at home in 2013	11.27	2.48	0	12
AC consumption	*AC energy consumption*	AC energy consumption (kgce)	12.71	22.06	0	255.41
	Annual AC usage time	Annual usage time of the first AC (hours)	289.25	254.15	0	1657.5

mean is 12.71 kgce (kg coal of equivalent), with a maximum value as high as 255.41 kgce, which is nearly 20 times the average level (see descriptive statistics in Table 1). In other words, energy consumption due to AC cooling is quite dispersed in different households. Further, the annual AC usage time, which is a continuous variable, has a mean of 289.25 h and a maximum value as high as 1657.5 h (which is nearly 8 times the average level); this implies that the annual AC usage time is quite dispersed in different households.

The average daily usage time refers to the average daily usage time of the first AC (the most frequently used one) if a household has more than one AC (in the sample, 730 households own only one AC, 42 households own a second AC, and only 4 households own a third). The average daily usage time is an ordinal variable that is divided into less than 2 h, 2–4 h, 4–6 h, and over 6 h. In our sample, the average daily usage time is distributed evenly in four intervals. Specifically, 25.89% of the households use ACs for less than 2 h in one day, 33.42% of the households use ACs for 2–4 h, 22.6% of the households use ACs for 4–6 h, and 18.08% of the households use ACs for over 6 h in one day.

Notes: In the survey, AC cooling energy consumption is calculated as follows: air conditioning cooling energy consumption

$$= \frac{rated\ air\ conditioning\ cooling\ power \times annual\ cooling\ time}{energy\ efficiency\ index}$$

3.3. Method

As mentioned above, this study used AC energy consumption and AC usage time as indicators of AC usage. For AC energy consumption and annual AC usage time, which are continuous variables, we use OLS models to study the effect of climate change on the AC energy consumption and annual AC usage time (see Table 2 Models 1.1–1.3 and Models 3.1–3.3). For daily AC usage time, which is an ordinal variable, we use ordered probit models to study the effect of climate change on the daily AC usage time (see Table 2 Models 2.1–2.3).

Table 2
Model specifications.

Model	AC energy consumption (OLS)			Daily AC usage time (Ordered probit)			Annual AC usage time (OLS)		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3
Meteorological variable	√	√	√	√	√	√	√	√	√
Income	√	√	√	√	√	√	√	√	√
Household characteristic		√	√		√	√		√	√
Household head characteristic			√			√			√

Estiri and Zagheni [20] study the relationship between age and energy consumption with OLS models that also contain CDD and household variables, and they add household information as control variables step-by-step beside the baseline model. In our study, we follow this method and regard Models 1.1, 2.1, and 3.1 as the baselines and add more household information to improve our models.

4. Results and discussion

4.1. Results for AC energy consumption

Though electricity price can be an important variable in explaining AC energy consumption, the electricity price data were not available. However, we included province dummies in the regression models to control for the provincial fixed effect. This would also capture the price effect because electricity prices within each province in China are nearly homogenous. The results for AC energy consumption are presented in Table 3.

From the results of Model 1.1 (column 1 of Table 3), which only includes household income and climatic variables, it can be seen that CDD has a significantly positive effect on AC energy consumption. This implies that the energy consumed by AC cooling increases when the household is located in an area where the temperature is higher and/or where the high temperature days last longer. Moreover, because ACs are powered by electricity, households located where the temperature is higher and/or high temperature days last longer, consume more electricity on hot days, which increases the burden of summer peak demand for electricity. The effect of relative humidity is insignificant, although its coefficient is positive. Further, the effect of income on energy use for AC cooling is positive but not statistically significant. In Model 1.2, where other household and dwelling feature variables were included in the regression, the effect of CDD is statistically significant as well. When the variables for the household head are included in Model 1.3, the main results still hold. That is, CDD has a significantly positive effect on households' AC energy consumption, and the effect of household income is positive but insignificant. It should be noted that we only focused on households that already have ACs. This result implies that income could play a less important role in the AC usage decision than in the AC purchase decision. Further, one can see from the results of Model 1.3 that working in the private sector could also have a positive impact on AC energy consumption. One possible explanation is that household heads who work in the private sector may pay more attention to quality of life, which leads to increased AC usage on hot days. That is, those working in the private sector are in some respects likely to be less conservative in terms of energy consumption.

Table 3
Results for AC energy consumption (linear regression)

VARIABLES	Model 1.1	Model 1.2	Model 1.3
income	2.53e−05	5.20e−05*	3.07e−05
	(2.47e−05)	(2.76e−05)	(3.05e−05)
CDD_2013	0.014**	0.019**	0.015*
	(0.007)	(0.007)	(0.008)
savgRHU	0.297	0.315	0.274
	(0.320)	(0.330)	(0.352)
household size		−0.627	−0.655
		(0.583)	(0.618)
dwelling size		0.179	0.264
		(0.494)	(0.521)
building year		−8.54e−04	−8.08e−04
		(0.001)	(0.001)
gender			2.769
			(3.046)
age			0.213
			(0.470)
age squared			−0.001
			(0.005)
work_public			−1.354
			(4.601)
work_private			8.825***
			(2.154)
ethnic Han			1.618
			(7.100)
edu_high			−0.785
			(6.440)
edu_low			−3.460
			(6.060)
living month			0.413
			(0.393)
Provincial fixed effect	yes	yes	yes
Observations	523	473	433
R-squared	0.169	0.169	0.225

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 4
Results for daily AC usage time (ordered probit model).

VARIABLES	Model 2.1	Model 2.2	Model 2.3
income	2.54e−06*	1.92e−06	2.26e−07
	(1.46e−06)	(1.61e−06)	(1.76e−06)
CDD_2013	0.002***	0.002***	0.002***
	(4.48e−04)	(4.73e−04)	(5.15e−04)
savgRHU	0.072***	0.080***	0.069***
	(0.019)	(0.020)	(0.021)
household size		0.005	−0.007
		(0.032)	(0.034)
dwelling size		0.008	0.040
		(0.028)	(0.030)
building year		−1.47e−04*	1.28e−04
		(8.49e−05)	(8.79e−05)
gender			0.0256
			(0.174)
age			−0.037
			(0.027)
age^2			2.97e−04
			(2.61e−04)
work_public			−0.051
			(0.266)
work_private			0.427***
			(0.123)
ethnic Han			0.399
			(0.428)
edu_high			0.127
			(0.385)
edu_low			0.176
			(0.361)
living month			−0.003
			(0.023)
Provincial fixed effect	yes	yes	yes
/cut1	6.290***	7.127***	6.297***
	(1.567)	(1.642)	(1.891)
/cut2	7.288***	8.116***	7.313***
	(1.574)	(1.650)	(1.898)
/cut3	8.143***	8.989***	8.227***
	(1.578)	(1.655)	(1.903)
Observations	522	489	445

Notes: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.2. Results for daily AC usage time

For the effect of climate change on the daily AC usage time, an ordered probit model was used; the results are shown in Table 4. In addition, we also calculated the marginal effects of variables based on Model 2.3 (see Table 5). It can be seen from Tables 4 and 5 that both the CDD and average daily relative humidity have statistically significant influences on the daily AC usage time. This suggests that the probability of increased usage of the first AC increases if a household faces a higher temperature, and/or if the high temperature days last for a longer time. Further, due to the fact that the rise of humidity will increase the perceived temperature in hot environments, the relative humidity is expected to have a positive effect on the AC usage time, which is consistent with our results.

The results also indicate that the year a household dwelling was built could have a negative effect on the daily AC usage time. That is, households in more recently built dwellings tend to use their ACs less. One possible explanation is that the new dwellings are better heat insulators, which makes ACs more effective and attractive, compared with households living in old buildings. Thus, there is no need for these households to cool the space over a long period of time. In addition, new buildings tend to have more efficient ACs, which could also reduce energy consumption for cooling. Moreover, consistent with the results for AC energy consumption, whether a household head works in the private sector has a significant effect on AC usage time (see the results of Model 2.3 in Table 4 and marginal effects in Table 5).

4.3. Results for the annual AC usage time

The results for the effect of climate change on the annual usage time are shown in Table 6, which indicate that both CDD and average daily relative humidity have statistically significant positive influences on the annual AC usage time. However, when household head features are included in the regression, the effect of CDD is not significant. This suggests that annual AC usage time increases if a household is located where temperatures are higher and/or the high temperature days last for longer. Further, the relative humidity is shown to have a significantly positive effect on the annual AC usage time, which is consistent with the results for daily AC usage time.

In Model 3.2, the effect of the dwelling building year on the annual AC usage time is also significantly negative, which implies that households living in a newer building tend to use ACs for a shorter period of time. The reason is similar to that for the results for daily usage time above; that is, new dwellings have better heat insulation ability, which makes ACs more effective and attractive compared with households living in old buildings. Further, it is noticeable from Model 3.3 that the dwelling size has a positive effect on the annual AC usage time, which means that households with bigger homes tend to use ACs more, which is consistent with our expectation. Moreover, consistent with the results for AC energy consumption and daily AC usage time, household heads working in the private sector have a significant effect on the annual AC usage time as well (see the results of Model 3.3 in Table 6).

4.4. Heterogeneity of the effect in different regions

To investigate the heterogeneity of the effect in different regions, we divided our sample into “North” and “South” groups based on China’s “Qin Mountains-Huai River” boundary [21]. The regression results are summarized in Table 7. It shows that the effects of weather variables

Table 5
Marginal effects from Model 2.3.

VARIABLES	Marginal effect			
	Less than 2 h	2–4 h	4–6 h	Over 6 h
income	−6.44e−08	−1.21e−08	3.13e−08	4.52e−08
	(5.01e−07)	(9.42e−08)	(2.44e−07)	(3.52e−07)
CDD_2013	−4.70e−04***	−8.81e−05**	2.28e−04***	3.30e−04***
	(1.43e−04)	(3.86e−05)	(7.19e−05)	(1.06e−04)
savgRHU	−0.020***	−0.004**	0.010***	0.014***
	(0.006)	(0.002)	(0.003)	(0.004)
household size	0.002	3.92e−04	−0.001	−0.001
	(0.010)	(0.002)	(0.005)	(0.007)
dwelling size	−0.011	−0.002	0.006	0.008
	(0.008)	(0.002)	(0.004)	(0.006)
building year	3.64e−04	6.82e−06	−1.77e−04	−2.55e−04
	(2.49e−05)	(5.11e−06)	(1.22e−05)	(1.77e−05)
gender	−0.007	−0.001	0.004	0.005
	(0.050)	(0.009)	(0.024)	(0.035)
age	0.002	0.001	−0.001	−0.002
	(0.001)	(3.64e−04)	(6.26e−04)	(9.90e−04)
work_public	0.014	0.003	−0.007	−0.010
	(0.076)	(0.014)	(0.037)	(0.053)
work_private	−0.122***	−0.023***	0.059***	0.086***
	(0.035)	(0.009)	(0.017)	(0.025)
ethnic Han	−0.114	−0.021	0.055	0.080
	(0.122)	(0.024)	(0.059)	(0.086)
edu_high	−0.036	−0.007	0.018	0.025
	(0.110)	(0.021)	(0.053)	(0.077)
edu_low	−0.050	−0.009	0.024	0.035
	(0.103)	(0.019)	(0.050)	(0.072)
living month	8.00e−04	1.50e−04	−3.88e−04	−5.61e−04
	(0.006)	(0.001)	(0.003)	(0.004)
Provincial fixed effect	yes	yes	yes	yes
Observations	445	445	445	445

Notes: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6
Results for annual AC usage time (linear regression).

VARIABLES	Model 3.1	Model 3.2	Model 3.3
income	1.99e−04	1.37e−04	−9.53e−05
	(3.03e−04)	(3.33e−04)	(3.59e−04)
CDD_2013	0.168*	0.174*	0.143
	(0.086)	(0.090)	(0.094)
savgRHU	16.010***	17.570***	16.460***
	(3.907)	(3.994)	(4.180)
household size		−3.978	−9.274
		(6.733)	(7.078)
dwelling size		8.509	14.570**
		(5.723)	(6.008)
building year		−0.027*	−0.027
		(0.016)	(0.016)
gender			45.540
			(34.960)
age			−2.092
			(5.479)
age squared			0.016
			(0.054)
work_public			−6.598
			(54.550)
work_private			76.780***
			(25.110)
ethnic Han			–32.530
			(84.230)
edu_high			−14.150
			(76.400)
edu_low			−34.730
			(71.810)
living month			3.569
			(4.653)
Provincial fixed effect	yes	yes	yes
Observations	522	489	445
R-squared	0.225	0.229	0.268

Notes: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

are more significant in the north region than in the south, implying that the change in cooling behavior due to climate change could be more noticeable in the north than in the south. One possible explanation is that households in the south region are already used to hot and humid weather, which leads to fewer adaption behavior changes than in the north region.

5. Conclusion and policy implications

Global warming and the increasing occurrence of extreme hot weather has become a major concern in the world. As an important coping strategy to climate change, the usage of ACs has attracted the attention of research studies worldwide. However, empirical evidence on the effect of climate change on household AC usage is still limited, especially in developing countries. This study employed the data from CRECS, matched with weather data, to analyze the effect of climate change on AC usage at the household level in China, using AC cooling energy consumption, average daily usage time, and annual AC usage time as indicators of AC usage. Moreover, our study focuses on rural China, which is representative of climate change adaptation behaviors in low-income countries or regions. Some scholars have already begun to pay attention to the relationship between climate and low-income nations. García and Graizbord [17] point out that, in Mexico, most strongly or extremely energy poor areas are rural areas with warm climates. Chen et al. [22] find that, for low-income households, residents living in warm areas have higher energy saving intentions because they abandon thermal comfort to save money. Our results explore how people from developing countries or low-income areas adapt to climate change and hot weather, which pushes the research on the relationship between climate change and AC usage in low-income areas forward.

The results show that CDD has a significantly positive effect on household AC cooling energy consumption and on the daily and annual AC usage time. When CDD increases, which means the temperature increases and/or high temperatures persist for a longer period of time, the AC cooling energy consumption for households will increase, which implies an increase of electricity consumption. This result is consistent with the review study by Mideksa and Kallbekken [18] on the topic of how climate change will impact electricity demand. Their review finds that studies, in general, conclude that higher temperatures are expected to raise electricity demand for cooling. Specifically, in terms of Chinese residential energy consumption behavior, our result is consistent with the household-level study of Li et al. [23], which finds that, on warm days, an increase in daily temperatures leads to an increase in electricity consumption in the Yangtze River Delta, China. At the same time, a larger CDD will also increase AC usage time.

While CDD has a significant influence on both AC energy consumption and usage time, average relative humidity affects only the AC usage time. An increase in humidity will increase the perceived body temperature in a hot environment, and it will consequently have a positive effect on AC usage time. In addition, we find that other socioeconomic variables—including dwelling age, dwelling size, and occupation—also influence AC usage.

Our study has two main policy implications. First, policy should encourage the use of high-efficiency ACs. The results show that climate warming will cause an increase in AC cooling energy consumption. Thus, although climate warming leads to increased AC use, we can improve AC efficiency to reduce the increase in cooling energy consumption. In China, the project "Benefit People from Energy-saving Products" has created a subsidy to encourage people to buy more powerful and efficient ACs. However, in our data sample, over 93% of households own ACs that are below the energy-saving standards. In other words, although the project encourages people to buy high-efficiency ACs, it does address the fact that so many people already own

Table 7
Heterogeneity of effect in north/south regions.

Dependents	AC energy consumption (OLS)		Daily AC usage time (ordered probit)		Annual AC usage time (OLS)	
	South	North	South	North	South	North
income	1.23e−06	7.01e−05	−2.00e−06	1.49e−06	−5.51e−04	5.20e−04
	(4.31e−05)	(4.28e−05)	(2.19e−06)	(3.20e−06)	(4.80e−04)	(5.92e−04)
CDD_2013	0.010	0.016*	7.20e−04	0.002^{***}	0.041	0.208*
	(0.014)	(0.008)	(8.62e−04)	(6.65e−04)	(0.160)	(0.116)
savgRHU	−0.833	0.533	−0.017	0.102^{***}	9.383	18.610^{***}
	(0.787)	(0.351)	(0.041)	(0.026)	(8.757)	(4.862)
household size	−0.755	−0.636	0.0125	−0.0231	−8.877	−8.625
	(0.956)	(0.726)	(0.049)	(0.053)	(10.660)	(10.050)
dwelling size	0.708	0.203	0.106^{**}	−0.014	18.000*	10.330
	(0.896)	(0.533)	(0.047)	(0.039)	(10.070)	(7.370)
building year	−4.66e−04	1.209	−1.15e−04	0.131*	−0.025	23.170*
	(0.002)	(0.929)	(9.06e−05)	(0.072)	(0.018)	(12.850)
gender	3.300	0.842	−0.287	0.211	27.270	43.560
	(4.878)	(3.305)	(0.253)	(0.247)	(54.270)	(45.730)
age	0.351	0.275	−0.066	−0.011	−4.262	−1.804
	(0.807)	(0.530)	(0.042)	(0.038)	(8.983)	(7.328)
age squared	−0.001	−0.003	5.67e−04	6.49e−05	0.043	0.014
	(0.008)	(0.005)	(4.00e−04)	(3.81e−04)	(0.086)	(0.073)
work_public	0.738	−2.353	−0.408	0.475	−20.630	12.010
	(7.155)	(5.623)	(0.374)	(0.399)	(79.640)	(77.800)
work_private	11.790^{***}	4.240	0.626^{***}	0.371*	106.500^{***}	55.190
	(3.322)	(2.677)	(0.174)	(0.197)	(37.010)	(37.040)
ethnic Han	2.406	0.365	0.290	0.660	−66.240	93.370
	(10.060)	(10.830)	(0.543)	(0.814)	(111.900)	(149.900)
edu_high	−3.506	4.617	−0.0241	0.554	−16.620	81.860
	(8.813)	(11.050)	(0.465)	(0.866)	(98.070)	(152.900)
edu_low	−4.666	1.239	0.030	0.636	−67.100	96.760
	(7.882)	(10.760)	(0.417)	(0.844)	(87.710)	(148.800)
living month	0.696	0.065	0.012	−0.023	7.732	−2.680
	(0.608)	(0.483)	(0.031)	(0.035)	(6.779)	(6.677)
Provincial fixed effect	yes	yes	yes	yes	yes	yes
/cut1			−1.824	10.280^{***}		
			(3.434)	(2.646)		
/cut2			−0.860	11.420^{***}		
			(3.435)	(2.664)		
/cut3			0.197	12.200^{***}		
			(3.435)	(2.674)		
Observations	237	209	236	209	236	209
R-squared	0.262	0.112			0.321	0.147

inefficient ACs and that these less efficient ACs will continue to be used since they are durable appliances. Thus, there should be a policy to encourage people to replace their existing low-efficiency ACs. Second, the study uses cross-sectional data to analyze the effect of climate change, which implies that the climate and temperature differences among different locations would lead to different AC usage. Therefore, when setting subsidies to encourage AC purchase or usage, policy-makers should take regional climate differences into consideration.

Furthermore, due to data's limitations, the potential effects of wind, precipitation, and other climatic facts are not accounted for, and we mainly focused on the intensive effect of climate change on AC usage. Further studies with more comprehensive panel data and dynamic models will facilitate the analysis of the more detailed effects of climate change on household adaptation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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