The what, why, and how of changing cooling energy consumption in India's urban households

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Abstract

India’s urbanising middle class is at the brink of an unprecedented increase in residential cooling demand, yet little is understood about the dynamics of changing cooling consumption. Based on empirical analyses, this research examines a set of fundamental questions around India’s cooling transition. How is cooling conceptualised and what cooling strategies do households use? How, when and why are people purchasing and using their air conditioners (ACs)? Who is buying energy-efficient ACs? Is cooling consumption gendered? Using descriptive statistics, machine learning, and regression analysis to characterize AC usage, we examine a sample dataset ($n = 2092$) that is representative of areas in Delhi with above average AC penetration. We unpack perceptions of thermal comfort, and characterize the conditions under which households have greater AC use and make energy efficient purchase choices. AC usage is found to be a function of household habits (such as exposure to ACs in the workplace or schools), structural factors, and socio demographic features. While most ACs are in the middle energy-efficiency range, preferences, behaviours and awareness around energy efficiency are found to affect AC use as well as influence the purchase of more efficient ACs. Notable gender differences are observed, and women are found to be less involved in decision-making around cooling appliances and less aware of the technical know-how or energy-efficient schemes. Policy recommendations for a low-carbon cooling trajectory are discussed.

1. Introduction

Over the past century, cooling technologies have fundamentally impacted the ways in which individuals interact with each other and their local environment (Seybold 2011). Cooling provides thermally comfortable indoor environments, increases productivity and protects health (Hitchings et al. 2014, Barreca et al. 2016). Today, energy use for space cooling is growing faster than for any other end use in buildings. 4.8 billion new units of cooling equipment are estimated to be sold globally between 2019 and 2030 resulting in a large rise in greenhouse gas emissions (Economist Intelligence Unit 2019). Understanding the growth in cooling demand, and finding ways to sustainably shape its trajectory remains a complex multidisciplinary task (Khosla et al. 2020a).

Much of the literature so far has focused on advanced economies, which have historically contributed the most to global cooling demand. Models project that in these countries, climate change induced demand for cooling will also be a significant driver of future electricity consumption (Auffhammer and Aroonruengsawat 2011, Jylhä et al. 2015, Wachs and Singh 2020). For the most part though, the global future cooling demand trajectory will be driven by developing countries like China, India and Indonesia. Indeed, studies estimate that air conditioner (AC) use in the developing world will lead to a 33-fold increase in global energy demand by 2100 (Sustainable Energy...
For All 2019). This is mostly led by increasing household incomes resulting in an increase in appliance ownership and subsequently, energy demand (Sivak 2009, Wolfram et al 2012, Gertler et al 2016, Challa et al 2019). Urbanisation and climate change are the other key drivers of the growth of cooling demand across countries (Isaac and Van Vuuren 2009, Akpinar-Ferrand and Singh 2010, Nematchoua et al 2019). For example, Davis and Gertler (2015) show how climate and income drive air conditioning decisions in Mexico. Hu et al (2020) found that single-split ACs replaced fans as the primary cooling appliance in Chinese urban residential buildings, with relationships between cooling use and income, education, culture and energy cost. Biardeau et al (2020) call attention to the global rise in air conditioning adoption and find that India has the highest exposure to increased cooling degree-days anywhere in the world.

Changing cooling consumption in India is particularly instructive as India ranks first among lower-middle income countries with an increasingly affluent middle class purchasing their first AC (Sustainable Energy For All 2019). While 8% of the current Indian households have room ACs, this is predicted to grow six-fold in less than 20 years (India Cooling Action Plan, 2019). The associated energy use is significant; in New Delhi alone cooling accounts for 40%–60% of the peak summer load (Abhyankar et al 2017). Simultaneously, evaporative air coolers which consume only 10%–20% of the electricity consumed by ACs continue to be popular with more than 55 million coolers nationwide (Alliance for an Energy Efficient Economy 2018). In terms of efficiency levels, it is estimated that if India’s existing market average efficiency of ACs is improved at 6% per annum, more than 64 TWh yr$^{-1}$ could be saved by 2030 (Abhyankar et al 2017).

These studies provide useful accounts of the magnitude of cooling needed in India for well-being and thermal comfort. Yet, almost none shed light on the dynamics of changing cooling patterns. Little is understood about what kinds of cooling options household seek, or how purchase choices are made. The pursuit of energy efficiency, too—for instance, who buys efficient technologies or uses technologies efficiently and why—remains underexplored. This paper aims to help fill the gap by asking a set of fundamental questions: How is cooling conceptualised and what cooling strategies do people use? How, when and why are people purchasing and using their ACs? Who is buying efficient ACs? And is cooling consumption gendered?

In answering these questions, this paper unpacks cooling energy demand in one of the fastest and largest urbanising regions of the world. Given that the demand for cooling is at the brink of the steep part of an S-curve, especially in India, the paper provides insight for impending transitions that are moving fast but are not yet locked-into path-dependent trajectories with significant implications for energy and climate futures (Creutzig et al 2016).

2. Methods

Understanding decision-making around purchase and use of cooling appliances requires a detailed examination of households that use these technologies and those which do not, within similar climatological, institutional and cultural realms. Such a data-set is not publicly available in the Indian context, where there is no countrywide residential energy survey so far.

We chose Delhi as a site to undertake this work as it is India’s highest electricity consuming region and its trends provide insight for the rest of the country (Khosla and Chunekar 2017). Further the rapid urbanization and huge population growth in Delhi over the past few decades has enhanced the urban heat island effect in the region leading to a further increased demand for cooling (Mohan et al 2020).

A door-to-door survey organized around eight modules was used to collect information on the spectrum of energy and cooling assets and their purchase, use and maintenance specificities, demographic and socioeconomic characteristics, and the socio-cultural factors and aspirations underlying cooling behaviours. Table 1 lists the key variables for which data is collected (see supplementary information (SI) annex A (available online at stacks.iop.org/ERL/16/044035/mmedia) for the full questionnaire and SI annex B for description of the survey design and implementation). Further, to rank households according to their ability to consume, an item-response model is used on the survey data to create an asset index using the survey data on appliances and vehicles owned (Khosla et al 2019).

We sought to identify the areas of Delhi with high AC usage, as this gives the most statistical variation for analyses of interest. To do so, we drew from a large representative dataset on the National Capital Region collected in 2016–2017 containing information on AC ownership and other assets (Chakravorty and Sircar 2020), referred to as the ‘baseline survey.’ As per the baseline survey, 24% of households in Delhi own an AC (Khosla 2020b). The basis of our sampling was the polling booth area that contains on average about 1000 voters and 200–300 households. We identified 108 polling booths with at least 30% AC ownership in the baseline survey over which 44.5% of households reported having an AC (compared to 13% who reported having ACs in the remaining polling booths in the baseline survey). We then drew a fresh random sample over these polling booths for a total sample size of 2092 households (see SI annex C for the sample protocol and characteristics). The sample is, thus, representative of areas in Delhi with above average AC penetration and avoids the pitfall
Table 1. Key material, socio-demographic and behavioural variables in the household survey.

| Category                     | Key household variables                                                                                                                                                                                                 |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Structural and built environment | • Floor level  
• Construction type (condition of walls and ceiling—concrete, semi-concrete etc)  
• Type of house (apartment, individual home, multi dwelling)  
• Number of rooms, halls, kitchens, balconies and their primary use  
• Quality of electricity supply (frequency of power cuts, voltage fluctuation etc)        |
| Economic and assets owned     | • Ownership status of the house (legal title, financing details, rental details)  
• Non-space cooling appliances owned  
• Vehicles owned  
• Primary cooking fuel used  
• Total monthly household income and expenditure  
• Electricity bills incurred (average, seasonal, excess due to AC usage)  
• Temporary residents (tenants, paid guests etc) hosted        |
| Demographic                   | • Caste and religion of the head of the household  
• Total number of household members  
• Age, gender, marital status of each member  
• Occupation status of each member  
• Highest level of education of each member  
• Years of domicile in the current house  
• Household’s migration status (inter-city, intra-city) and reasons for migration  
• Travel history of members        |
| Cooling appliances            | • Fans  
• Number of fans owned  
• Features—Brand, Efficiency (rated or not)  

• Coolers  
• Number of coolers owned  
• Features—Brand, Age, Ownership (Gifted or purchased), Price  
• Usage patterns—Rooms with coolers, Hours used, Time slots of extensive use  

• Air Conditioners  
• Ownership—number of ACs, type of AC (window/split), nature of ownership (new, second-hand, gifted), mode of purchase (paid in installments), source of purchase (retailer, online)  
• Features—brand, rating, tons, warranty, price, age, temperature control (dial-knob, remote, digital)  
• Usage—default settings, frequency of user engagement (temperature adjustments), rooms with AC, hours used, time slots with extensive use, primary reason for use, activities undertaken during AC use  
• Maintenance and servicing requirements—frequency, cost, reasons for breakdown        |
| Behaviour and awareness       | • Concern for climate change and the degrading state of environment  
• Knowledge of star-ratings, LED scheme, and meaning of star rating stickers seen on ACs and fridges  
• Knowledge of per unit electricity cost  
• Use of electricity saving strategies while cooling house with AC (regulating usage or temperature)  
• Use of non-energy using cooling strategies (opening doors/windows, consuming cold drinks etc)  
• Members involved in the decisions for AC purchase and use (buying, switching the AC on/off) |

of non-representativeness of purposive sampling. All told, 43.4% of the sample households reported owning ACs, of which 11.6% had more than one AC, enabling a rare (near 50–50) split of AC and Non-AC households in representative sample data.

The survey was conducted in July–September 2019 to ensure high recall value of cooling use during the hot summer. Table 2 provides the sample summary characteristics of the 9334 individuals in the entire sample of 2092 households, and the 4124 individuals in the 907 AC-owning households. The sample has greater penetration of white goods compared to Delhi as a whole, implying relatively wealthier neighbourhoods (table 3). Note that AC ownership comparisons are not possible with national level data due to limited publicly available data on AC penetration. Specifically, India’s decennial census does not capture any data on ACs and the five-yearly National Sample Survey Organization combines air coolers and ACs as one category. The Indian Human Development Survey (IHDS) is the only national survey that measures AC ownership as a separate variable, however it does not collect detailed information on the units of AC owned by a household.
and its last available dataset is from 2011 to 12 rendering it as dated in the context of India’s fast urban growth.

The analysis in the paper uses a combination of descriptive statistics (sections 3 and 4), variable selection methods from machine learning, and regression analysis to characterize AC usage (section 5), energy efficient choices (section 6), and awareness about energy choices by gender (section 7). The regressions employ a Least Absolute Shrinkage and Selection Operator (LASSO) model, employed to understand how much of the variation in AC usage is predicted by the full set of 66 predictors. In SI annex D, we discuss the robustness of the method chosen, by applying other standard variable selection techniques like stepwise forward and backward selection. We demonstrate how the key results discussed in sections 6 and 7 are substantially similar regardless of the method chosen, with LASSO additionally addressing the issue of ‘overfitting’ the data for accurate measurement of explained variation while selecting the predictors that are most consequential for AC usage.

We assess the relative importance of these predictors on AC usage using ordinary least squares (OLS). To examine the drivers of energy efficient (or ‘star-rated’ as termed by the Indian government) ACs, we similarly use a LASSO to select variables 56 plausible predictors of the star-rating of the most used AC, and use OLS to understand the relative importance of various factors in predicting the star-rating of the AC and the proportion of the variance explained. See SI annexes E and F for the LASSO model outputs, and annex D for the full regression results.

### 3. What cooling appliances are people buying?

The starting point of understanding cooling patterns is to examine what comprises cooling options. We consider three types of cooling appliances in their respective order of penetration: fans; air coolers; and ACs. While most homes have a combination of fans and coolers (and not ACs), a third have fans and ACs (and not coolers). Only 11% of homes have all the three cooling devices (figure 1).

![Figure 1. Ownership of cooling appliances in the sample households. The percentages in the diagram represent the proportion of all households having the given appliance. The actual number of households for each appliance ownership category is listed in brackets.](image)

#### Table 2. Socio-economic characteristics of the sampled population in Delhi (2019).

| Characteristic                                      | Full sample (with AC and non-AC) (N = 9334) | Sample with ACs (N = 4124) | Baseline survey—Delhi (2017) |
|----------------------------------------------------|---------------------------------------------|-----------------------------|------------------------------|
| Female (%)                                         | 47.6                                        | 47.1                        | 45                           |
| Scheduled caste (%)                                 | 22.4                                        | 16.3                        | 15.8                         |
| Average number of occupants per household          | 4.5                                         | 4.5                         | 4.5                          |
| Average number of rooms per household              | 4.5                                         | 5.3                         | 2.6                          |
| Average age (years)                                | 33.6                                        | 35.6                        | 32.7                         |
| Working age group 15–64 years (%)                  | 76                                           | 77.2                        | 76.7                         |
| Employed males in working age-group (%)            | 73.6                                        | 75.4                        | 65.3                         |
| Employed females in working age-group (%)          | 13.2                                        | 16.0                        | 9.3                          |
| Individuals who completed schooling (%)            | 41                                           | 54.5                        | 34.7                         |
| Average reported monthly household income (INR)    | 12 496 (166.9 USD)                          | 15 687 (209.57 USD)         | —                            |

*Using conversion rate 1 USD = 74.85 INR.

#### Table 3. Comparison of white goods penetration in Delhi.

| Appliance               | Sampled data (2019) | Baseline survey (2017) |
|-------------------------|----------------------|------------------------|
| TV (%)                  | 94.5                 | 96.4                   |
| Fridge (%)              | 89.2                 | 89.3                   |
| Washing machine (%)     | 70.9                 | 54.3                   |
| Room air-conditioners:  |                      |                        |
| • One unit (%)          | 38.3                 | 19.1                   |
| • Two units (%)         | 4                    | 4                      |
| • Three units or more (%) | 0.9                 | 1.2                    |

#### Figure 1. Ownership of cooling appliances in the sample households. The percentages in the diagram represent the proportion of all households having the given appliance. The actual number of households for each appliance ownership category is listed in brackets.
median fan-owning house owns two. Seventy-eight per cent of fans are branded as opposed to being locally assembled. Only 7% of the households report having an energy-efficiency rated fan, likely because fans are currently voluntary under the Government’s Standards and Labelling program (Bureau of Energy Efficiency (BEE) 2019). Despite being in the wealthiest and most electricity consuming part of India, approximately 18% of the households have fans as their sole cooling device—pointing to the range of cooling options within a relatively small geography.

Coolers are the next most popular cooling appliance. Approximately half of the surveyed households have one cooler—22% of which also own an AC. Coolers were usually purchased within the last four years and 88% of coolers were locally assembled. On average, the retail cost of branded coolers is INR 4500 (USD 60), twice as expensive as unbranded ones.

ACs are owned by 43.4% of the households—of which 88% own a single AC and 9% own two ACs. Split ACs are slightly more popular (56.3%) than window ACs (43.5%) (Figure 2). Eighty-seven per cent of ACs were bought new, while 8% of ACs were second hand and 4% of ACs were gifted. In most cases, the AC had a capacity of 1.5 tons, and were purchased in the last 2–3 years. The relative newness of AC purchase demonstrates the rising trend of cooling uptake in urban India. On average, new ACs tend to cost three and half times more than their second-hand counterparts, with the average price of a new AC at INR 30 367 (USD 405).

Over 90% of all ACs are branded. Interestingly, 78% of AC owning households have at least one energy efficient rated AC. A three-star rated AC (mid-range of energy efficiency) is the most popular choice followed by the most efficient five-star (figure 3), with an average price differential of 20% between the two models. Interactions with local retail stores reflect these findings—most stores stock three-star rated ACs (with or without inverter technology) based on average consumer usage, followed by five-star ACs, and have limited four-star rated ACs.

4. How are people purchasing their ACs?

The analysis uncovers key characteristics of how an increasing number of people purchase ACs. Ninety-eight per cent of new ACs were bought at a retail store. Forty-eight per cent of second-hand ACs were bought from a local store, 45% were from a friend/relative, and less than 5% were bought online.

The decision to purchase an AC is made by the head of household (usually male, middle aged and employed) or by the head’s offspring, who are involved in all stages of the purchase process, from deciding which appliance to purchase, to scouting for options (figure 4(a)). Even in cases where the purchase was a joint decision, the head or their offspring were the primary decision makers in almost all cases.

The most important factor driving AC selection is the company brand followed by the features that the AC offers (figure 4(b)). Less than 5% of the households reported energy efficiency ratings as a reason for determining which kind of AC to buy, suggesting the relatively low level of priority towards environmental or energy saving avenues. Approximately half the ACs were financed in installments.

Ninety-four per cent of the AC-owning households reported the major factor in purchasing their
first AC was either cooling need or ineffectiveness of existing cooling appliances, while less than 10% of the households reported the purchase as a result of augmented economic status. The majority of the non-AC households reported not switching to ACs yet due to prohibitive costs, with close to 90% citing high prices of ACs and nearly 40% stating high recurring costs like electricity bills and maintenance.

5. How are people using their ACs? Understanding decisions around increased AC consumption

As emerging economies move towards increased cooling consumption primarily from ACs, how people use their ACs is a vital question in understanding changing cooling consumption, and in informing measures to move towards low-carbon lifestyles. Next, we examine the characteristics and lifestyles of the households where the AC is increasingly used.

Sixty per cent households use the AC for an average of 3–6 h daily during peak summer months (figure 5). Even in the wealthiest neighbourhoods, during the hottest months of the year, only about 15% of households use ACs for more than 8 h day. By contrast, the national India Cooling Action Plan estimates cooling demand by considering that everyone who owns an AC runs it for over 8 h a day for 6 months of the year (MoEFCC 2019).

Within these AC use hours, a range of preferred temperatures are sought. Results show that almost half the households set their AC temperatures between 24 °C and 26 °C (figure 5). Twenty-seven per cent prefer the AC temperatures between 21 °C and 23 °C. The relatively large 5 °C range in the temperatures that households consider comfortable, even under the same weather conditions, is an important reminder of the heterogeneity in the perception of thermal comfort. Further, studies suggest a 5%–6% energy use change per degree increase in thermostat set-point temperature (Manu et al 2016). Overall, 24 °C is reported as the most preferred temperature setting for Delhi’s summer (ambient temperatures of 28 °C–35 °C) (New Delhi Climate (India) 2019). 24 °C is also the default setting for room ACs as mandated by India’s government in 2020 (Press Information Bureau 2020).

AC usage hours also vary across households. In most cases, the AC and cooler are used between 10 pm and 1 am suggesting the prioritization of cooling during sleep (figure 5). The next most frequent timeslot is 1–4 pm. Many households report switching off the AC in the middle of the night or when they leave the room. The AC is usually controlled by either the offspring (38%) or by the head of the household (33%). AC use is not the only cooling strategy that households use and 72% of the AC owning households reported using a non-AC cooling strategy (figure 6). Of these, fan use is the most popular followed by coolers. Close to 10% of AC owning households also use passive cooling measures such as natural ventilation to adapt to the heat.

The average number of hours AC usage is 5.4 h in our sample. We use the LASSO and OLS regressions to understand the drivers of AC use in the households. The statistical results are captured in table 4, with key predicted effects in figure 7. We interpret the regression coefficients as a change in the usage from a baseline in which each other predictor is held at its mean value.
We find that, a standard set of built environment and structural factors predict AC usage. Residing above the ground floor (1.7 h or 35% higher usage on average), living in apartments as opposed to houses (1.1 h lower usage on average), and having poor power supply (0.9 h lower usage on average) are all significant factors in driving AC usage. Yet even after controlling for wealth effects, the regression analysis reveals that thermal preferences, behavioural factors and awareness of energy efficiency are as important as these standard structural factors.

Interestingly, those who set their thermostats to 19 °C or lower are predicted to have 1.6 h higher usage on average, suggesting a certain stickiness of cooler comfort temperatures. Those who report needing the AC for sleeping, studying, or working are predicted to have one hour higher usage on average. Furthermore, as the proportion of household members exposed to an AC at work or school grows from 0 to 1, we expect the average hours of AC usage to grow from 5.2 h to 7.1 h for a 37% increase in the usage of ACs. Households who recommend buying ACs to their friends and family also use ACs for an average of 0.7 h or 13% more.

Awareness about energy efficiency, bills, and savings is also found to be an important determinant of AC consumption. Those who know about the subsidized LED bulbs scheme, know about per unit cost of electricity, and own rated fans are predicted to have 0.5, 0.7, and 0.9 h of AC usage respectively. Naturally, the regressions show that households that practice electricity saving strategies use their AC less.

Finally, socio-demographics are important determinants of AC usage. Houses with higher reported monthly incomes use the AC for longer. Those with more second-hand ACs, a higher proportion of seniors (aged 60 and above), and families who have not moved home for long periods use the AC for fewer hours.

6. Who has energy efficient ACs?
Understanding environmentally sustainable decision-making

Next, we examine the characteristics of households that choose energy efficient ACs. In the sample, the average star rating was 2.8, with a three-star rating being the modal category. Higher price and low availability are two key factors that prevent people from buying a more efficient AC (figure 8). On the other hand, energy and electricity bill savings, and environmental consciousness, are the most common reasons for opting for four- and five-star ACs (figure 8).

Using LASSO for variable selection and OLS regression, we characterize the conditions under which households use an energy efficient AC table 5 provides the regression results, and figure 9 displays the marginal effect of key predictors (in terms of...
Table 4. Who is using more AC? (Regression Results).

| Dependent variable: | Total AC hours |
|---------------------|----------------|
| Total no. of temporary residents | -0.229*** (0.086) |
| Difference between summer and winter electricity bills (in INR) | 0.0003*** (0.0001) |
| Those who cannot do some activities without AC | 0.951*** (0.292) |
| Floor: first floor and above | 1.670*** (0.373) |
| Reported monthly income of households (in INR) | 0.00002*** (0.00000) |
| Proportion of members with AC at school/workplace | 1.909*** (0.674) |
| No. of ACs | 4.040*** (0.651) |
| Total no. of ACs with a less than three-star Rating | -1.979*** (0.676) |
| Total no. of ACs used at a temperature of 19°C or less | 1.617*** (0.421) |
| Total no. of second-hand ACs | -1.471*** (0.556) |
| Length of stay in current house (in months) | -0.0002*** (0.0001) |
| Have power cuts | -0.516* (0.239) |
| Have a poor electricity supply | -0.877** (0.447) |
| Use a voltage stabilizer for AC | 0.568* (0.283) |
| Reported last monthly electricity bill (in INR) | 0.0001* (0.00004) |
| Know the per unit cost of electricity | -0.656* (0.306) |
| Type of house: apartment | -1.121** (0.484) |
| Proportion of members aged 60 years and above | -1.032** (0.485) |
| Asset score | -0.267*** (0.128) |
| Aware of Ujala LED scheme | -0.499*** (0.245) |
| Adjust temperature/switch-off AC before sleeping | -0.719** (0.296) |
| Own rated fans | -0.873*** (0.376) |
| Will recommend friends/family to buy ACs | 0.699*** (0.301) |

Observations 849  
R² 0.416  
Adjusted R² 0.389  
Residual std. error 3.317 (df = 810)  
F statistic 15.196*** (df = 38; 810)

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Figure 7. Marginal effects on AC usage (Hours) for key predictors.

Star rating) of purchasing more energy efficient ACs holding all other predictors at their mean.

Beyond cost factors, the key factors in the decision to buy higher efficiency star-rated ACs relate to awareness. Households that know the meaning of energy efficiency stickers are predicted to have a higher rated AC by one star. Furthermore, households with more senior citizens are less likely to own an efficient AC.

Efficient cooling investment decisions are also guided by select AC characteristics. Heavily used window ACs have on average a 0.44 (15%) lower star-rating than split ACs, and second-hand ACs have on average a 0.56 lower star-rating than new ACs. The scale of cooling matters too. Larger homes are associated with efficiency (one more room in the home predicts on average a 0.09% higher star-rating on the most-used AC). Households which give preference to AC features (e.g. having a remote, heating mode etc) over the technology brand are predicted to have a 0.35 (12%) lower star rating.
7. Is cooling consumption gendered?

Energy and gender studies converge on how households are not homogenous units and every individual’s outcomes and aspirations are different. Coen-Pirani et al. (2010) highlight how the diffusion of household appliances like washing machine and freezers freed up women’s time and led to their increased labor force participation in the US in the 1960s. Other studies suggest how policies to attenuate energy consumption have a higher influence on women than men and that women are usually more likely to conserve energy (Carlsson-Kanyama and Lindén 2007). Malik et al. (2020) discuss gender power dynamics within low-income housing in Bombay, India with non-working women reporting the use of an AC in the presence of a male member.

The surveyed results show that the decision of purchasing a cooling appliance is primarily made by the male, middle-aged, employed, head of the

Table 5. Who has an efficient AC? (Regression Results).

| Dependent variable: | AC’s rating |
|---------------------|-------------|
| Proportion of members aged 60 and above | -1.045∗∗∗ (0.279) |
| Type of AC (by style): window AC | -0.443∗∗∗ (0.126) |
| Age of the most used AC (in months) | -0.006∗∗ (0.002) |
| Owns rated fans | 0.525∗∗∗ (0.187) |
| Knows the meaning of stickers on ACs/fridges | 1.035∗∗∗ (0.132) |
| Type of AC (by ownership): second-hand | -0.559∗∗∗ (0.211) |
| Most important factor while choosing AC: features | -0.350∗ (0.161) |
| Total no. of rooms | 0.087∗∗ (0.041) |
| Has a Power Backup | 0.281∗ (0.131) |
| Reported price of most-used AC (in INR) | 0.00001∗∗∗ (0.0000) |

Observations: 709

R²: 0.314

Adjusted R²: 0.261

Residual std. error: 1.523 (df = 658)

F statistic: 6.011∗∗∗ (df = 50; 658)

Note: *p < 0.1; **p < 0.05; ***p < 0.01.
household, followed by their offspring. In approximately 80% of the households, the head’s spouse caters to domestic duties. The spouse can be a secondary decision maker when appliance related decisions are made jointly. Work from other countries shows similar results of traditional gender power divisions where men often make major household purchasing decisions despite not spending much of their time at home (Fingleton-Smith 2018).

The lack of women’s involvement in the decision-making process is underscored in the Delhi sample. Sixty per cent of the survey respondents are females with some say in household finances allowing a comparison between the survey responses from men and women. The significance of the difference in mean responses by the gender of the respondent was measured using two-sample t-tests. Figure 10 shows the distribution for the statistically significant results (p-values < 0.05) by the gender of the respondent. The general level of awareness of energy related policies and schemes was found to be lower for women, with significantly fewer women knowing of the government’s energy efficiency programmes. Women also reported knowing the meaning of energy efficiency stickers seen on refrigerators and ACs at a relatively lower rate compared to their male counterparts. Fewer women report being familiar with the specificities of their ACs such as the brand, efficiency rating, capacity and warranty period. This gap in appliance related know-how is further reflected in the finding that women were more likely than men to not have any preference in deciding which AC to purchase.

While all home members are beneficiaries of a cooling appliance, the decision-making and its technical awareness was highly skewed towards men. Interestingly, women also explicitly expressed concern for the degrading state of environment and climate change at significantly lower rates. This might stem from a link between lower levels of awareness, technical know-how and prevalent gendered practices. These results, which are different from those of other geographies where women play a much stronger environmental role, highlight how understanding the role of women in cooling energy decisions remains a core area of future work.

8. Discussion and recommendations

Rapid urbanization, increasing incomes, and rising temperatures are driving more Indians to buy space cooling appliances. Over 300 million residential ACs are expected to be purchased in the next 20 years (MoEFCC 2019). While access to adequate cooling is needed to keep people healthy and productive, it comes at a cost of intensive energy use and greenhouse gas emissions. Moving towards a low-carbon cooling pathway requires understanding the factors that are driving this increased use of ACs. A few strategic results and policy implications emerge from this empirical work.

The purchase of energy intensive cooling appliances is relatively recent. Even within the geography of one city, 43% of the households in the sample own one AC, while 18% in the same neighbourhoods own only a fan. This setup provides a unique opportunity to tap first-time buyers and incentivize purchase of more efficient appliances. The current mode of cooling appliances in the sampled households are inefficient fans and coolers, and ACs with an average mid-level energy efficiency rating of three-stars. Interventions that rapidly scale up the energy efficiency of cooling appliances—at a speed that matches the fast rate of increasing AC and cooler penetration—will be essential to locking-in low-carbon thermal comfort.

Awareness of energy efficiency schemes is also key to the initial purchase decision. Households better
informed about available schemes purchase more efficient technologies, and use these technologies more efficiently. Evidence from other parts of the world also shows that information campaigns have a constructive effect on guiding efficient energy consumption (Kang et al 2012, Hu et al 2020, Sharifi 2021). Further, there are distinct intervention points at which promoting awareness is particularly helpful. One, the local retailer plays a vital role in influencing purchase decisions and providing the range of efficient options available as most new ACs are bought here. Second, cost is important to the purchase of ACs and as majority of the ACs are financed in instalments, innovative financing mechanisms that promote efficient purchases and replacement of inefficient ACs are likely to succeed. These findings align with others in the literature, particularly the work of Abhyankar et al (2017).

How a cooling appliance is used post-purchase provides its own opportunities for low-carbon behaviours. The duration, time of use, and temperature setting of the AC varies significantly within the city, emphasizing that there is no one-size-fits-all measure of thermal comfort. Households use ACs for an average of 5 h a day, which is a much more judicious compared to assumptions made in modelling projections of residential cooling demand. However, exposure to ACs in the workplace and schools is found to influence the preference of households to use their ACs for longer, as does the proclivity for lower thermal comfort temperatures. As the most common use of the AC is for sleeping, time of day pricing could also help lower the afternoon and night-time peak demand.

The results also show the differentiated roles of men and women in AC decision-making. Middle-aged men usually decide when and which AC to buy, and control its use when installed, while, women report lower levels of energy-related expertise and awareness. Targeting and working with men and women differently can be important in changing the approach towards cooling efficiency. Reaching out to women is especially relevant, as comparative work shows that higher energy awareness in women can lead to positive outcomes from energy conservation interventions (Carlsson-Kanyama and Lindén 2007). Analogously, interventions and awareness drives for specific age-cohorts, such as senior citizens, can be useful as demonstrated by this study.

Finally, in spite of the focus on AC consumption it is equally relevant to emphasize, understand and encourage the prevalent role of non-air-conditioning based cooling. Such cooling strategies can be electricity consuming (e.g. turning on the fan), electricity saving (e.g. all members occupy one room, switching off the AC before sleeping), or non-electricity consuming (e.g. adjusting clothing, opening windows and doors). Recovering and promoting passive cooling alternatives from building design, shading, vegetation and myriad other ways will be core to meeting future cooling needs in a low-carbon manner. Analogous and complementary work is suggested from across different geographies (Oliveira Panão 2014, Invidiata and Ghisi 2015, Ulpiani 2021).

As cities across India urbanise it is likely that the projected increase in cooling demand will be largely met—not least because of the growing access and ability to add new ACs and fulfil the aspirations of modernity that ACs embody. This study helps unpack the characteristics of the households that are making this change and the conditions under which cooling is increasingly used. Much future work is needed for empirical results to inform modelling projections of cooling demand. Further surveying and monitoring is also necessary to understand cooling behaviour across regions, especially due to the limited availability of data on AC ownership at a national level. Together, these are critical steps towards providing sustainable cooling to all.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Environ. Res. Lett. 16 (2021) 044035

R Khosla et al
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