Staying cool in France: an extensive survey of summer comfort, natural home cooling practices and emerging air conditioning use in the French residential sector

Mathieu Durand-Daubin
EDF R&D
7 bd Gaspard Monge
91120 Palaiseau
France
mathieu.durand-daubin@edf.fr

Guillaume Binet
EDF R&D
Av. des Renardières
77250 Écuelles
France
guillaume.binet@edf.fr

Marie-Hélène Laurent
EDF R&D
Av. des Renardières
77250 Écuelles
France
marie-helene.laurent@edf.fr

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Abstract

According to the International Energy Agency, over the next three decades, the use of air conditioners is set to soar, becoming one of the top drivers of global electricity demand. In France, as summer heatwaves become more frequent, the residential air conditioners installation rate doubled in the last ten years, bringing the total share of equipped dwellings to 25 % in 2021. To tackle the increase in energy consumption and changes in seasonality that could result from this trend in the future, we need a better understanding of current cooling practices. So far in this country, while heating consumption in winter caught all the light, little was known of energy consumption in summer. This paper offers an analysis of French households' summer cooling practices based on a unique representative survey of 8,000 households, asked about their building and equipment, comfort, everyday natural ventilation and shading actions, and cooling appliances usage. We show how the diversity of summer comfort and temperature perception depends on building features, location, and heat waves. Natural cooling is still more frequent than the use of air conditioners. During summer 2021, most people regularly opened windows in the night and morning, and closed shutters in the middle of the day, while only half of the households with air conditioners used them in addition to natural cooling. Air conditioners use rates and set temperatures depend on comfort perception and the types of cooling equipment. Air conditioning is mostly occasional and space specific, as opposed to the norm of constant cooling that can be found in other parts of the world. Altogether, this detailed description of current cooling practices, their interactions and drivers, allow to anticipate a limited rise of this demand, shall people keep on their natural ventilation and shading actions.

Introduction

According to the International Energy Agency (IEA, 2024), over the next three decades, the use of air conditioners (AC) is set to soar, becoming one of the top drivers of global electricity demand. Given projected future growth of cooling demand and AC ownership worldwide, a major concern is that climate change-driven increases in the frequency and intensity of extreme temperatures will amplify electricity demand (Colelli, 2023). Based on the IEA 2018 figures, Randazzo (2020) described how between 1990 and 2016 annual sales of AC nearly quadrupled to 135 million units, which tripled global energy demand for cooling, reaching about 20 % of the total electricity use worldwide in 2018. At that time, China led the world with 41 million residential units registered, followed by 16 million in the US, and roughly 9 million in both Japan and Europe.

INCREASING SUMMER COOLING NEEDS AND THE RISE OF AIR CONDITIONING IN EUROPE

Until now, in Europe, air-conditioning accounts for less than 1 % of total residential buildings energy consumption (in 2021, according to Eurostat, 2024), while heating in winter accounts for the highest energy use with 65 % of the sector demand. This share of energy consumption dedicated to cooling can still be higher in southern countries such as Malta, Cyprus and Greece, reaching 11 %, 10 % and 5 %, respectively (ibid.). In compari-

son, in the United-States, with an AC ownership rate as high as 89 % in 2020 (EIA, 2024) cooling accounted for 10 % of total household energy consumption, compared to 44 % for heating. Much of these differences between Europe and North America may be attributed to climate (Randazzo, 2020), but other factors also play a large part, including expectations of thermal comfort (Henderson, 2005), historical institutional factors (Colelli, 2023), higher diffusion rates of technologies resulting from higher affordability, and higher window-to-wall ratio, higher thermal insulation and increased air-tightness in buildings (Mayrhoffer et al., 2023, based on Thibaut & Delmastro, 2020 and Silva et al., 2022). However, even in countries located at mid-latitudes, the frequency of days with very high average temperature is rising, and therefore also the demand for space cooling (Randazzo, 2020). Moreover, extreme heat in European buildings is not only a climate and comfort issue, but also a health and social justice issue. Heatwave events caused 77,000–129,000 deaths in the 32 European Economic Area member countries between 1980 and 2020, representing 86 %–91 % of fatalities caused by climate-related extreme events (European Environment Agency, EEA, 2024).

The combination of rising temperatures, aging population and increasing standards of living leads more and more people to buy and use AC to keep themselves cool. Air conditioning household equipment rates in Europe rose from 14 % in 2010 to approximately 20 % in 2019 (ibid). In France, the residential air conditioners installation rate doubled in the last ten years, bringing the total share of equipped dwellings to 25 % in 2020, according to the French Agency for the Environmental Transition (ADEME, 2021a). This trend is expected to continue as the French government anticipates a temperature increase by 4 °C in France (Mainland) by the end of the century (CNTE, 2023). Does this mean that Europeans are becoming "more like American households" as questioned by Henderson in 2005, leading Europe cooling consumption to catch up with the high demand observed in the United-States? To answer this question, we need to know more about how AC are used, and if alternative or complementary "passive" cooling measures are taken by occupants.

THE ROLE OF COOLING BEHAVIOURS

In addition to building design and energy efficiency, occupants' behaviour and awareness could play a key role in the mitigation of cooling energy demand (Andreou et al. 2020; IEA, 2024), and in limiting the overheating of buildings and protecting occupants' health, maintaining an indoor environment of good overall quality (EEA, 2022). The EEA lists urban cooling, and passive cooling as key elements of a sustainable strategy in which active cooling – air conditioners usage – is used "rationally".

Use of air conditioning: set temperature, time and space

In homes where AC is used, energy demand for cooling depends on the indoor temperature required (set temperature), the duration of use, and in which rooms it is used. Different standards for these three demand parameters can be found throughout the world, as illustrated by the cases of the United States, the Netherlands and India. In the United-States (EIA, 2024), the most common set temperature during the day is around 23 °C (51 % of users when at home, 44 % when out), while lower temperatures can be required at night (lower than 20.5 °C for 30 % of AC users). Higher temperatures are accepted when out (25 °C and more for 32 % of users). In this country, AC target temperature can be set once and for all (as practiced by 42 % of users), or be adapted manually, by adjusting the set temperature (23 %) or turning the appliances on and off (17 %). Using a programmer only happens in 15 % of the cases. In the Netherlands, a survey conducted by Rovers et al. (2022) shows that the tipping point above which people turn their air conditioner on is around 25 °C. Set temperatures range from 18 °C to 22 °C across households and are lower in the bedroom and for portable AC than for fixed AC. The time of use varies depending on the room (living, workspace, bedroom) according to the respective occupation time: during the daytime for living rooms and workspace, and during the evening and night for bedroom. In India, where the diffusion of air conditioners is relatively low (less than 10 % of households), a survey carried out across three distinct climatic areas (Kaur et al., 2022) shows approximately 70 % of respondents use AC with temperatures set at 23 °C or below during summers as well as monsoons with strong regional and seasonal variations. They depict ACs as being most predominantly used for 6 to 12 hours in a day, with longer durations in the bedroom.

In France, ADEME recommends not to use AC when indoor temperature is under 26 °C (ADEME, 2021b). The normative method used in the French building code to estimate the energy consumption dedicated to space cooling (3CL-DPE 2021 method, described in RT-RE, 2021) considers a set temperature of 28 °C should be "conventional" while 26 °C is described as "excessive spending". These normative calculations also tend to consider indoor maximal temperature requirements to be constant and uniform across the building, inspired by what was assumed for heating in winter.

"Passive" or natural cooling behaviours: shading and night time ventilation

In its policy document, EEA (2022) suggests to "prioritise passive cooling solutions, such as summer shading, night and day natural ventilation, and very low energy consumption options, such as well-designed ceiling fans." Already in 1998, passive cooling was considered to play a significant role in reducing our rising carbon footprint (Roaf et al., 1998). In this quest for passive cooling, some researchers put forward the quality of building design and features (Hermelink et al., 2022, Ozarisoy, 2022, Kuczyński et al., 2021), while others insist on the primacy of occupants' behaviour (Mayrhofer et al., 2023, Silva et al., 2022). These solutions not only apply to residential buildings but also to commercial buildings (Artmann et al., 2007, Mayrhofer et al., 2023). Based on simulations, Mayrhofer et al. (2023) find that ambitious passive adaptation measures, combining increased shading (two-fold), night ventilation (five-fold) and higher indoor temperature (+2 °C), could save up to 82 % of energy consumption dedicated to cooling in Austria in 2050, corroborating the results by Silva et al., who found 84 % of cooling consumption could be saved in Switzerland based on similar methods. They also argue that in spite of lower effectiveness of night time ventilation in the South of Europe, it is still able to significantly reduce energy demand and increase thermal comfort in Mediterranean climates, when combined with external shading. Solar shading and natural ventilation

can indeed significantly improve thermal comfort in southern Europe, as shown in Spain (Figueroa-Lopez et al., 2021, Borghero et al., 2023). Borghero et al. also found that users' behaviour reduces energy consumption in summer more than retrofitting, and ventilation with fans can prevent overheating while consuming little energy. At the European level, Ozarisoy (2022) claims that architectural passive design strategies on newly built terraced houses could reduce cooling energy consumption by 53 %. Kuczyński et al. (2021) attempted to experimentally verify the combined effectiveness of the three most commonly used passive methods reported in the scientific literature in a temperate climate: night ventilation, exterior blinds, and heavy thermal mass in comparable existing rooms of an actual building. Across these studies, shading proved as the most effective measure to reduce cooling demand (by up to 60 % for Mayrhofer et al. 2023) or significantly lower indoor temperatures (cf. Kuczyński et al.). However, several studies point at the risk, that heatwaves of future years will degrade the efficacy of passive cooling strategies (Mayrhofer et al. 2023, Borghero et al. 2023).

CURRENT COOLING BEHAVIOURS IN FRANCE

In this paper, our contribution to the evaluation of the risk of a strong rise in energy demand for cooling in Europe, and its possible mitigation, is to investigate how French households currently manage to keep cool within their homes. How much do they rely on the use of air conditioning units, which multiplied over the past two decades? What kind of technology is installed? Does the equipment installed for the dominant winter heating usage have an impact on summer cooling equipment? Do users follow institutional guidelines regarding the use of AC (indoor temperature and set temperature at 26 °C), or do they express higher demand like in other countries. Is AC used in summer with the same regularity as heating systems during winter, or does it follow some singular ad hoc usage pattern? Furthermore, we want to know the current frequency of passive cooling behaviours, such as strategic window and shutter management and natural ventilation, which provide natural cooling. Could AC ownership have a negative impact on natural cooling behaviours? How does AC usage and cooling behaviours vary across the population?

To answer these questions, we analysed the results of a survey of space cooling practices ("cooling survey"), in France (mainland) residential buildings, based on a sample of 8,000 households, launched at the end of the 2021 summer. The data collected describe households and buildings features, the number and types of air conditioners in use, how they are used, declared temperatures, and the frequency of shading and natural ventilation behaviours.

Data

THE "COOLING SURVEY" AND THE CONSER SURVEY

In this paper, most of the results come from a survey conducted by EDF R&D in Autumn 2021, which is named the "cooling survey". The aim of this study is to examine in detail how households deal with summer heat and how they manage their homes, appliances, air conditioners along with a large variety of cooling habits (from "passive" habits (i.e., shading, windows opening) to "active" habits (i.e., air conditioning and all the combinations in between)). The 45-minute-long questionnaire was filled in online by more than 8,000 respondents, representative of the French residential population with regards to seven characteristics: age, socio-professional category, region, town size, household size, building type, housing occupation status. A second survey, referred as CONSER, was also conducted by EDF R&D in early 2023. This study focuses on home electrical appliances also covering air conditioning (ownership rates and management). It was also an online survey representative sample of French households (4,000 households with the same characteristics as in the "cooling survey").

Building features and AC technologies

Our "cooling survey" starts with a standard sociodemographic description of the household. Then, follows a detailed description of the building they live in, room by room, covering purpose, size, openings, and insulation. Air conditioning equipment can be divided into two families:

- portable air conditioners (wheeled, they can be moved from room to room) and
- fixed heat pumps (which cannot be moved).

The fixed heat pumps family covers 3 technologies:

- Air-to-air heat pumps (the most common for air conditioning), extract energy from outside air and circulate fresh air in the home via indoor units (in the room or centralised in association with air ducts.
- Air-to-water heat pumps (not very common in air conditioning), also extract energy from outside air but distribute cooled water into the home via a water underfloor network. It refreshes indoor air.
- Geothermal heat pumps (rare in air conditioning), extract energy from the ground and distribute cooled water into the home via a water underfloor network. It refreshes the indoor air and does not cool it.

For households with an air-to-air heat pump as their main air conditioner, two possibilities are available, as described below:

- Single split: one outdoor unit for each indoor unit of the heat pump.
- Multi split: one outdoor unit for several indoor units of the heat pump.

Heat Pumps used for air conditioning are often technically able to generate heat. If so, they are known as reversible heat pumps. In this paper, we will refer to portable air conditioners as "portable AC" and heat pumps used for cooling or refreshing the air as "Air Conditioners" (AC). Geothermal, air-to-water and multi-split heat pumps can cool several rooms of the building, while single split and portable systems are dedicated to one room.

The technologies used by households for cooling and/or heating are the subject of two consecutive parts in the "cooling survey". A first part was dedicated to the identification of all of the equipment that can be used for heating, cooling, or both (reversible), and check the consistency of the declared combinations: mobile air conditioner, reversible or non-reversible

air-to-air heat pump, reversible air conditioner, reversible or non-reversible air-to-water heat pump, reversible or non-reversible geothermal heat pump. Air-to-air heat pumps were offered under two different headings – air-to-air heat pumps and reversible air conditioners, to make sure all of them are captured. In a second part, questions were asked to refine the characteristics of each owned item: number of pipes for mobile air conditioners, number of outdoor and indoor units for air-to-air and air-to-water heat pumps, type of indoor units for all heat pumps. The indoor units are described room by room. Combining rooms information and AC systems allowed to compute the share of floor area that can be actively cooled.

AC use and natural cooling behaviours

In our "cooling survey", heat perception and cooling behaviours were investigated in two steps: general summer habits, and daily cooling routines during Summer 2021. All data collected is declarative.

In the first part, all respondents were asked about how they generally deal with heat in their current home: shading, ventilation, reducing the use of appliances producing heat (e.g., cookers or air dryers). Different levels of answer were allowed and adapted to the different cooling behaviours. For instance, some people close all their shutters in the afternoon, while others only close part of them depending on when sunlight strikes in specific windows. In some analyses, to simplify, these behaviours were aggregated into three levels: not at all, partially, entirely. All the questions were repeated for two different situations: on a normal summer day or during a heat wave. This way we wanted to understand how people change their behaviour in reaction to increased heat stress. All households were also asked how often they suffered from excessive heat, in 2021, in which room and at what time of the day.

In the second part, only people who declared using air conditioning during the summer 2021 were asked systematic questions about their daily behaviours during that time. Questions were repeated for four types of days defined by: how hot it was (normal summer day or heat wave) and if someone was at home during the day or not. For each room, at five different periods of the day (morning, noon, afternoon, evening and night), people were asked about: the temperature in the room, if someone is in the room, if AC is on, AC set temperature, if windows are open, if shutters are closed. In addition to this systematic collection of daily patterns, AC users were asked more general questions, among which the number of days during the year on which they used AC and the outdoor temperature level above which they turn on AC.

These data allowed us to describe the intensity of "active" (AC) and "passive" (natural) cooling, how they interact and what are their main drivers. Most of these analyses relied on the comparisons of behaviours frequency and average values, crossed with variables depicting different contexts (e.g., type of building). Additional multivariate analyses were used: regressions to explain who suffered from heat and who adopts natural cooling behaviours; Multiple Correspondence Analysis (MCA) to explore which features are shared by the same households.

SUMMER WEATHER AND HEAT WAVES

Cooling equipment rates and behaviours were analysed with respect to households' characteristics and local cooling needs. Cooling needs in France depend greatly on the location. Part of these variations can be measured by the total Cooling Degree Days (CDD) calculated for each climate zone (Figure 1) in the French building regulation (RT-RE, 2021). Annual CDD (Table 1) measure the total number of degrees (°C) by which daily average outside temperature exceeds a reference temperature (26 °C) across one year. The H2d area, South-East but distant from the shore, has to cope with 143 CDD, while Brittany (H2a) only faces 12. In some of the following analysis, for simplification, we use clusters of these climate zones: northern areas (H1a, H1b, H2a, H2b), South-East (H2d, H3), South-West (H2c), and Center (H1c).

As a consequence of global warming, heat waves are expected to be more frequent, longer and hotter, during French summers (RTE, 2021). In the recent past, France was particularly affected in 2003, 2006, 2018, 2019, and 2022, reaching a peak of mortality in 2003 with an estimated death toll of 15,000 people (ONERC, 2023).

Regarding the summer of 2021 at the end of which our survey was carried out, it was exceptionally mild, with no se-

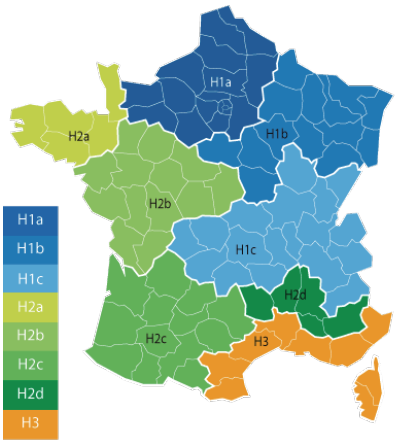

Figure 1. French Climate Areas. Source: https://expert-bati-conseil.fr/rt-2012-re-2020/les-zones-climatiques-en-france-h1-h2-ou-h3/.

Table 1. Cooling Degree Days (base 26 °C) by French Climate Areas (RT-RE, 2021).

Area	CDD	Area	CDD	Area	CDD
H1a	17.61	H2a	11.77	H3	100.15
H1b	33.67	H2b	27.53		
H1c	50.19	H2c	55.02		
		H2d	143.06		

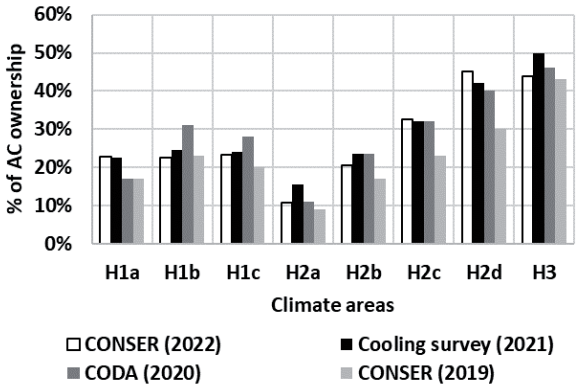

Figure 2. Main Air Conditioning system (2021, France (mainland), % households).

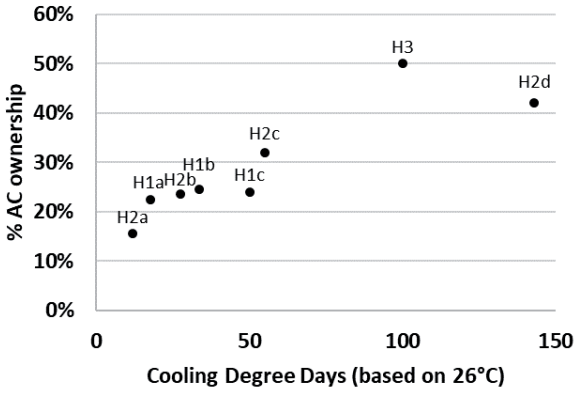

Figure 3. Households equipped with AC vs CDD (cooling degree days).

vere heat waves. Even if some parts of the questionnaire do not focus on this specific summer, one must consider that answers collected could have been influenced by these mild conditions.

Results

FEELING TOO HOT AND DECLARED INDOOR TEMPERATURES

According to our "cooling survey", despite the mild weather, nearly half (47 %) of the French population suffered from hot weather during the summer 2021: of which 39 % occasionally, and 8 % for all the duration of the summer. We estimated a logistic regression model of this summer discomfort (suffering from heat, at least occasionally vs. not suffering from heat in 2021) depending on the dwelling description (climate area, altitude, type of building, building age and floor area). Results show that there are significantly more people suffering from hot weather when living in a small flat, at the top of an old building, located in the South-East of France at a low altitude (detailed results are not developed in the paper). Among those combining all these factors, 63 % suffered occasionally, 12 % during all of the summer.

Respondents who declared using their AC during the summer 2021 were asked about their indoor temperatures in various situations. Average declared temperatures varied between 19.5 °C at night, on mild days in most regions, and 24 °C in the afternoon of hot days (heat waves) in the South of France. The most frequent temperature varies across day and night: 18 °C at night, 20° in the morning, 24 °C at noon, 25 °C in the afternoon, and finally 22 °C in the evening. People suffering from hot temperatures differ mainly from others by more frequent (but still marginal) indoor temperatures reaching 30 °C. The next two sections will explain how French people manage their heat comfort with air conditioning and with natural cooling behaviours.

AIR CONDITIONER OWNERSHIP IN FRANCE

According to the "cooling survey", the rate of air conditioning (any type) in France (mainland) was 24.6 % in 2021, or more than 7 million households equipped. This rate is similar to the periodic estimates made in the "CONSER" surveys (21.7 % in 2019, 25.8 % in 2022) and the estimate in the CODA survey (ADEME, 2021a) (25 % in 2020) for ADEME.

The equipment rate is higher for households living in houses (27 %) than for those living in flats (21.5 %). There is also a marked disparity between climatic zones: the 3 surveys show the same trends in equipment rates according to climatic zone (Figure 2). The equipment rates by area are logically correlated with the severity of summer climate (Figure 3). However, the AC ownership rate for the H2d area is a little lower than expected given its extreme 143 CDD. This rate might be inaccurately estimated due to the limited number of respondents in this area, as this region represents a small proportion of households compared to the population in France.

What kind of equipment is used for air conditioning?

The results given below are expressed as a % (or number) of households equipped, and describe the main cooling equipment, that is the one declared as being the most intensively used.

In the French residential sector (all types of building), most of the air conditioning (Figure 4) is provided by fixed heat pumps – HP (66 %), almost exclusively air-to-air heat pumps (62 % of total air conditioning). Geothermal heat pumps and air-to-water heat pumps are not common for main air conditioning (4 %).

The other large contingent is made up of portable air conditioners, which account for 34 % of main household air conditioners (29 % in houses and 41 % in flats). The reality of the "air conditioning" service provided by this type of equipment is questionable: almost half of these mobile air conditioners are declared not to have air supply and/or extraction pipes. Although households perceive this type of equipment as air conditioners, it can't exchange heat with the outside environment. They are more like "improved fans". If this type of device is not counted as an actual AC, the rate of equipment would drop to 20.3 % instead of 24.5 %. Most (61 %) of the households using an air-to-air heat pump use single-split technology (Figure 5).

Suffering from hot weather also has an impact on AC ownership. In particular, people who felt too hot all the summer 2021 have higher rates of single split (13 %) and portable AC ownership (10 %), when compared to those who never felt hot, 10 % and 7 % respectively.

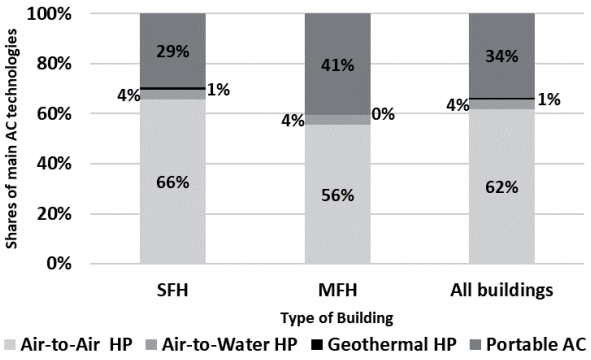

Figure 4. Main Air Conditioning system (2021, France, mainland, households). SFH: Single Family House, MFH: Multi Family House.

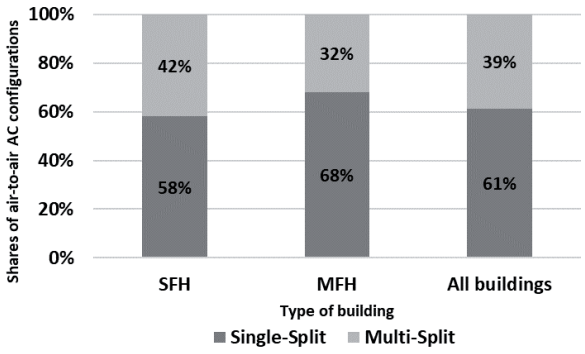

Figure 5. Air-to-air HP single-split and multi-split configurations (2021). SFH: Single Family House, MFH: Multi Family House.

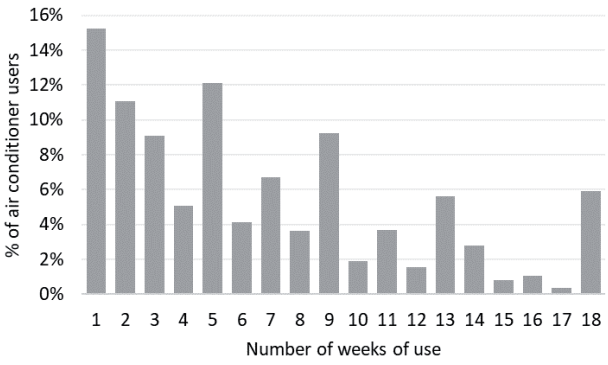

Figure 6. Number of weeks of use of AC in 2021.

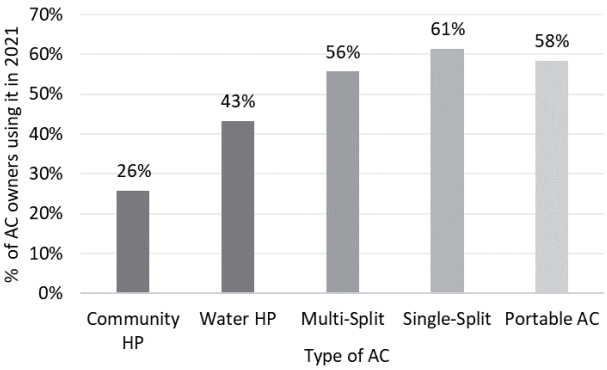

Figure 7. Use rate by type of AC technology.

AC equipment combinations and rooms coverage

Several AC systems configurations can allow to cool several rooms in the building: heat pumps circulating cold water (4 %), multi-split (24 %), and combinations of similar or different pieces of equipment. In some rare cases, different types of AC can be combined in the same household: 4 % of the main air-to-water heat pumps are associated with a split system, and 3 % of primary air-to-air heat pumps are combined with a mobile AC. Overall, these configurations allow AC to cool a part of the floor area: 30 % on average, 24 % in houses, 43 % in flats.

Reversibility of air conditioning equipment: rate of use of air conditioners for heating purposes

Out of 6.4 million households equipped with fixed heat pumps, 26 % only provide heating, 29 % perform main cooling and main or secondary heating, 46 % only provide air conditioning and at best a little heating. Among AC owners, 61 % say that their main air conditioning equipment could technically be used for heating: all air-to-water and geothermal heat pumps, 72 % of air-to-air heat pumps and a surprising 27 % of portable air conditioners. Most of households equipped with a heat pump for AC use their indoor units for heating (84 %). Because of air conditioning only cooling a small part of the building, unlike with heating, ACs used for heating are not so often the main heating system: 44 % of the reversible ACs. This is much more the case for the rare geothermal (100 %) and air to water systems (73 %).

AIR CONDITIONING USAGE

AC use rate

Among people owning at least one air-conditioner (25 % of the French population), a little more than half (57 %) used air-conditioning during summer 2021. Some used AC just a few days (less than a week for 15 %) while at the other end of the range (Figure 6) others declared using it 3 months (5.5 %) or even 4 months (6 %) from June to September. Overall, only half of AC users used it more than one month (median is 32 days), leading to an average 43 days of use (25 days if we count AC owners who didn't use it at all). The use of AC also depends on the type of technology (Figure 7). During summer 2021, owners of portable (60 %) and air-to-air heat pumps (70 %) were more likely to use them than those with reversible air-to-water heat pumps (30 %). These differences could result from air-to-air systems being primarily installed for cooling purpose, while air-to-water systems are more likely to be used first for heating, even if they offer cooling capacity. Among air-to-air systems, portable ones represent lesser investments possibly associated with more occasional needs.

Intensity of use per day: space and durations

Among users during summer 2021, respondents stated to use their AC slightly more when a heat wave strikes than on normal summer days. On days of use, in nearly half of the cases, AC is used only in the living room (Figure 8), and in 25 % of the

cases only in the bedroom. In terms of duration, it is used all day long for between 45 % and 65 % of users in different rooms, with longer duration when a bedroom is involved. Only 15 % of the population use AC during one specific period of the day, usually in relation with the room occupancy (during the day in the living room, during the night in the bedroom). Overall, on days of use, the AC is on for a mean duration between 70 % and 80 % of the day. People using AC just during heat waves, use it only a part of the day, making the share of users cooling all day decrease during these days. Overall, among AC users in 2021, considering the average number of days of AC use is 43 days, and AC is used 75 % of the hours on these days, on average AC is declared to be used 774 hours in the season.

Rates of cooling per period of the day (not displayed here) range from 35 % to 90 % of people who declared using AC in the room at least once. When used, reversible air-to-water heat pumps are used at stable and higher rates, while portable AC use changes depending on the period of the day, home occupancy and in the event of a heat wave. Bedrooms receive more cooling by the end of the day, especially in the evening, less so in the morning.

Temperature of use: outside and set temperatures

The outside temperature triggering the use of AC (Figure 9) ranges from 20 to 45 °C, with most of the AC owners choosing a value among 20 °C, 25 °C, 28 °C, 30 °C and 35 °C. The mean and median temperature is 28 °C just between the two main modes 18 % at 25 °C and 25 % at 30 °C. On hot days, set temperatures lie mainly between 20 °C and 25 °C, 22 °C also being a frequent value for all systems. This value is higher for reversible water-based systems, and lower for portable conditioners. These differences are likely to result from technical limitations on low temperatures for systems using water. They can also be related to the steady use of the first systems running in the background with little adaptation to varying needs, while later systems are used actively in reaction to heat peaks. In some cases, temperatures as low as 15 °C were reported, though it is unlikely the system actually reaches these low temperatures. Instead, presumably some people use low temperature settings thinking it will speed up the cooling of the room, as it was reported in some other studies (Kaur et al., 2022). This behaviour could also be a sign of possible discrepancies between people needs and AC capacity (whether not adapted or misfunctioning). Overall, median and mean set temperatures are around 21 °C. If temperatures lower than 19 °C are excluded for not being actual set temperature, mean set temperature rises to 22 °C. When outdoor temperature is higher, in the afternoon of hot days, AC temperature is set on a higher value around 22 °C, as if people were limiting the gap between indoor and outside to avoid uncomfortable contrasts.

NATURAL COOLING BEHAVIOURS

While AC is available to 25 % of the population only, cooling behaviours are possible for everyone. For summers in general, a large part of the French population declares regular behaviours preventing heat gains during the day (closing shutters and windows, reducing their use of cooking or washing appliances) or cooling down their home by extra ventilation when outside temperature is lower, at night or early in the morning (Figure 10). Only 4 % declare doing nothing of these, 3 % in the event of a heat wave (None of "any behaviour" in Figure 10).

Main cool conservation behaviours

After keeping windows closed in the afternoon, which requires little dedication; opening windows in the morning (and/or at night) is the most frequent cooling behaviour (Figure 10), with varying levels of engagement (night and/or morning, part or all of the windows and shutters). On a standard summer day, opening in the morning is the most frequent (more than 80 % do it partly, 32 % entirely) while during a heat wave there is more of a balance between morning and night opening (around 70 % partly and 35 % entirely, for both). Preventing heat and sunlight to come inside during the day is less frequent on a normal day (60 % partly, 15 % entirely), but increases more during a heat wave (75 % partly, 30 % entirely). Avoiding internal heat gains by reducing the use of some appliances, especially cooking, is less common (15 %), but increases a lot during a heat wave (to 35 %).

A significant part of the population combines the closing of shutters and windows during the day, with cooling at night and in the early morning (65 % do some of each on a normal summer day, 76 % during a heat wave – these specific combinations are not visible in Figure 10). For the more engaged, 22 % (33 % during a heat wave) are doing everything but cooking reduction, 4 % (14 % during a heat wave) are doing everything possible including cooking reduction.

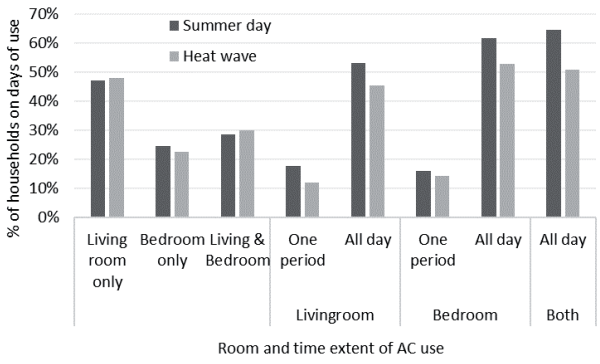

Figure 8. AC use per room and share of the day.

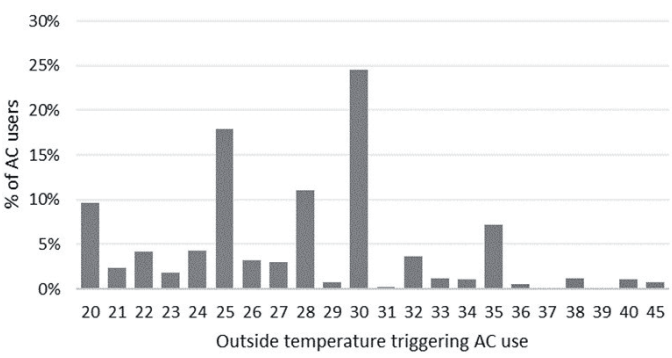

Figure 9. Outside temperature when AC is used.

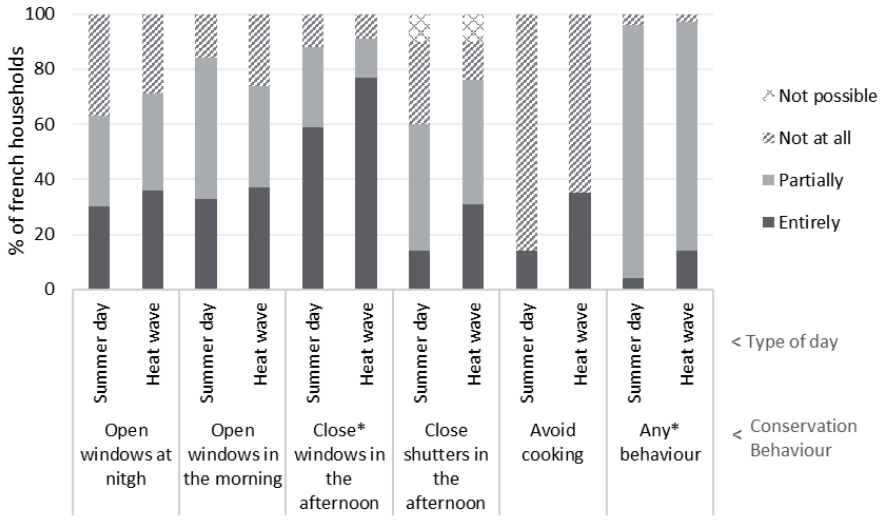

Figure 10. Declared natural cooling behaviours in the French population.

**Closing windows in the afternoon doesn't require enough engagement to be fully counted as a conservation behaviour. It's not counted in "any behaviour". It is still displayed because not doing it is responsible for cool losses.*

Table 2. Models of the level of natural cooling behaviours.

Factors	Value	Windows Opened in morning	Windows opened at night	Windows closed in afternoon	Shutters Closed in afternoon	Avoid Cooking
	Intercept	0.58 ***	0.32 ***	0.68 ***	0.37 ***	0.09 ***
Type of day	**Heat wave** (vs. Summer day)	-0.03 ***	0.24 ***	0.11 ***	0.15 ***	0.22 ***
Climate Zone	**H1c** (vs. H1abH2ab)	0.00	0.03 ***	0.06 ***	0.08 ***	0.04 ***
	H2c (vs. H1abH2ab)	0.01	0.03 **	0.08 ***	0.08 ***	0.05 ***
	H3-H2d (vs. H1abH2ab)	0.01	0.09 ***	0.02 *	0.11 ***	0.03 **
Building	**Detached House** (vs. Appartment)	-0.02 ***	-0.06 ***	0.06 ***	0.08 ***	-0.03 ***
AC owned	**Portable AC** (vs. no AC)	0.00	-0.05 ***	0.01	0.02 *	0.06 ***
	Fixed AC (vs. no AC)	-0.01	-0.11 ***	0.00	-0.02 **	0.02 *
Suffered from heat	**Sometimes hot** (vs. never)	0.03 ***	0.03 ***	0.01 *	0.05 ***	0.06 ***
	Hot all Summer (vs. never)	0.02	0.04 ***	-0.04 ***	0.06 ***	0.11 ***

significance: * p<0.05, **p<0.01, ***, p<0.001

Time of the day and specific situations

The systematic inquiry of people behaviour by room and period of the day allows a more detailed description of the spatiotemporal dynamic of natural cooling (for people using AC that summer). On a summer day, closing shutters peaks in the afternoon, at the same time as perceived indoor temperature, and is higher in the living room, where it reaches the same level as in the bedroom at night (55 %). Opening windows reaches 40 % in the morning in both rooms, 35 % at night. Both behaviours are much less frequent when the room is not occupied, except for the living room at night where shutters are closed, and windows opened a little more when nobody is in the room. These two behaviours are particularly rare when the bedroom is not occupied at night.

Who is doing what?

There are differences in the level of engagement in cooling behaviours, and we want to know how these differences relate to contrasted cooling needs (e.g., outside temperature and type of building) or the use of AC as an alternative cooling means. A multiple correspondence analysis (MCA) of geographical areas, building features, heat perception and natural cooling practices shows a few links between these variables. Mainly, on a usual summer day, in the South-East (H3 and H2d weather area), where suffering from heat most of summer is more frequent and AC ownership higher, people close their shutters during the day and avoid cooking more than others, even on a normal summer day. However, these regional features tend to weaken during a heat wave.

The influence of the context on each of the five natural cooling behaviours was estimated more precisely by means of a set of generalised multiple linear regressions. Each regression model estimates the extent to which one of the conservation measures is put into practice (between 0 for not at all to 1 for entirely, e.g.: all windows, systematically) as a function of the factors. The advantage of the multiple regression is that effects are estimated while taking into account the effect of other factors. For this analysis, climate zones were grouped based on their CDD, from lower to higher cooling needs: the north half (H1a,b, H2a,b), a central part (H1c), the South-West (H2c) and the South-East (H3, H2d). In Table 2, each column holds the coefficients of one regression. These coefficients show the effect

of the explanatory variables' (in line) values on the conservation measures (in column): positive values stand for an increase in the occurrence of the behaviour, negative values express a decrease. Coefficients not marked with stars are not significantly different from 0, meaning this factor value has no effect on the behaviour. Results show that the happening of a heat wave is the most influential factor, producing a strong increase in night ventilation and reduction in cooking activities. It comes with a light reduction of morning ventilation, probably caused by higher outside temperature at that time. Those declaring suffering from heat are involved in more cooling behaviours, shading and reduced cooking, in particular. However, those suffering more often also tend to have their windows open more often during the day. Regional zones have differentiated effects on behaviours: no effect on morning ventilation, more shading in the afternoon in the South half of France than in the North half (reference area), more night ventilation in the South-East area (H3, H2d), closed windows in the afternoon in the South-West and Center. Living in a house increases daytime conservation behaviours but reduces ventilation at night. Overall, natural cooling behaviours during summer 2021, for those who used some kind of air conditioning, doesn't differ dramatically from the whole population. The main difference is AC owners are less likely to open their windows at night to bring in some cool air from outside.

Discussion

Thanks to the size and representativity of the "cooling survey", we built an overview of the current state of space cooling in the French residential buildings, and we were able to dive into the diversity of people behaviours. However, it should not be forgotten that the information collected in a survey is declarative, which necessarily implies approximations due to interpretation, lack of memory or knowledge, and biases towards desirable responses.

AC EQUIPMENT

The 25 % rate of AC ownership we found in our survey is in the range of what was described in prior studies, with consistent underlying variations between climate areas from 10 % to 50 %. For a large part, this equipment is made up of air-to-air heat pumps and portable AC, which are in majority primarily dedicated to cooling. In comparison, reversible systems installed for heating in winter are more often based on water heat distribution and make a small part of the cooling capacity. Their role in actual cooling is even less significant when we consider their use rate is 15 % lower than for air-to-air devices. Hence, heat pumps installed for heating purpose do not contribute significantly to the rise of cooling consumption in France. The other way around, a part of air-to-air AC devices initially dedicated to cooling provide some efficient heating in winter, but almost always as a secondary support, as they are often limited to one room.

While this confirms the past rising trend of AC ownership in the country, it does not mean that every building equipped with air conditioning is fully air-conditioned. In most dwellings, AC is present in only one room, as opposed to what is observed in the United-States where 70 % of AC are central systems distributing cool in several rooms (EIA, 2024). On average, in France, only 30 % of the floor area can be cooled, with multi-splits being the main option (24 % of the total AC stock) offering to cool several rooms. Moreover, the efficiency of a significant part of the AC devices is questionable as half of the declared portable AC (34 % of AC equipment) could be "improved fans" rather than actual thermodynamic machines. The large part of portable devices in itself could be a sign of the immaturity of the French air conditioning market, in that this type of equipment is still largely purchased as a stopgap, particularly in response to heatwaves, rather than being integrated into the building upstream (ADEME, 2021b). Portable devices being more frequent in apartment buildings than in houses, they could also reflect a lack of practical alternative solutions in a context of stronger architectural constraints, and promiscuity. In that case, it could help to involve condominium managers, to anticipate and find more efficient collective solutions. At a larger scale, urban policies aiming at reducing heat islands, would also greatly help.

AC USAGE

People do not cool all indoor space continuously. Unlike for heating (Durand-Daubin et al., 2022), as a natural consequence of AC often being installed in one room, only small parts of the dwellings are air-conditioned. AC is used only in the living room in nearly half of the cases, and only in the bedroom in 25 % of the cases. The times of use and duration of use per day depend on the room, its occupancy, the type of AC, and outside temperature. Overall, in spite of this flexibility, on days of use, AC is used all day long in more than half of the cases, while short periods of use are much less frequent, contrary to what was observed in India.

The outside temperature declared to trigger the use of AC varies around 28 °C (median), with 25 % of the population indicating 30 °C. Considering these heat sensitivity levels, only 57 % of AC owners used their equipment during the mild summer 2021, showing that in spite of the increasing number of AC, a large part of them is not used systematically. In this context, the number of days of use ranged from a few days to three months, with half of AC users over one month of use, and an average 43 days of use. Overall, an average AC user declared using AC for cooling during 774 hours in 2021 (8.5 hours per summer day). This is consistent with the number of hours of use derived from the normative calculations based on a reference temperature of 26 °C (RT-RE, 2021), which ranges between 250 hours (climate zone H2a) and 1,200 hours (climate zone H3).

However, when AC is used, the set temperatures declared in our survey are lower than expected, with a raw median of 21 °C. These results show that people do not follow the public guidelines (ADEME, 2021b) suggesting a cooling temperature of 26 °C, even if they come closer on hot days, adapting indoor temperature to external temperature, possibly to avoid a strong thermal contrast. Information campaigns would be needed to promote more sustainable cooling temperatures and make the 26 °C standard as well-known as the 19 °C standard for heating. These set temperatures are still consistent with those declared in the Netherlands (Rovers et al., 2022). These observed low set point temperatures could reflect two distinct phenomena. On the one hand, the high number of people choosing a set temperature of 20 °C, could be a default choice, for its centrality, as an abstraction of a balanced neutral comfort, as it is also

frequently used in winter for heating system as seen in Durand-Daubin et al. (2022) On the other hand, values under 20 °C and as low as 15 °C, that were found in other surveys (Kaur et al., 2022), could reflect a practice, which would consist in using the set temperature as an indicator of the power used for quicker cooling, instead of being a temperature to reach. This would be consistent with the observation of lower set temperatures when using portable AC, which are also more frequently turned on and off than central AC, which is used more constantly.

NATURAL COOLING

Most of French households are not equipped with any AC systems. A large part of them still manages to cope with summer heat in most situations (only 8 % consistently suffered from heat in 2021), adapting shading and ventilation to their cooling needs. Natural cooling is widespread (96 % implement at least one behaviour), with differences in the level of engagement (4 % declare doing everything possible, even on a normal summer day), and adaptations to external conditions. The rates of shading and internal heat gains limitations increase a lot in the event of a heat wave. AC owners use air conditioning in addition to traditional cool conservation measures, with little impact on these traditional practices. They still tend to do less natural ventilation, opening windows less often at night. Both manual heat management and air conditioning depend strongly on the presence of occupants at home or in specific rooms. Given existing adaptations and the wide base of people declaring some kind of natural cooling, we could expect an intensification of these behaviours in reaction of increasing summer temperatures and more frequent heatwaves. Moreover, quiet and safe environments are required for night ventilation. New buildings and retrofitting programs should optimize flows for natural ventilation and offer convenient adaptable options for shading (in our survey 10 % of the buildings do not have shutters).

Conclusion

Overall, the use of air conditioning in residential buildings remains low in France, while most households still rely on traditional gestures, protecting from the sun in daytime and bringing in cool air at night. Contrary to heating equipment, most air conditioners are used on a limited number of hot days, to cool parts of the dwellings. However, when used, people declare lower set temperatures than recommended, showing a potential need for better information and learning on how to use AC sustainably. This learning is needed to mitigate the effect of the potential growth in AC ownership on summer electricity demand. It is even more necessary to help people keep engaged in their natural cooling practices, by means of convenient and adaptable buildings offering passive solutions, as well as improved urban environments. On this last aspect, heat island mitigation, noise and insecurity reduction can all ease ventilation at night, while more trees and plants can contribute to shading.

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